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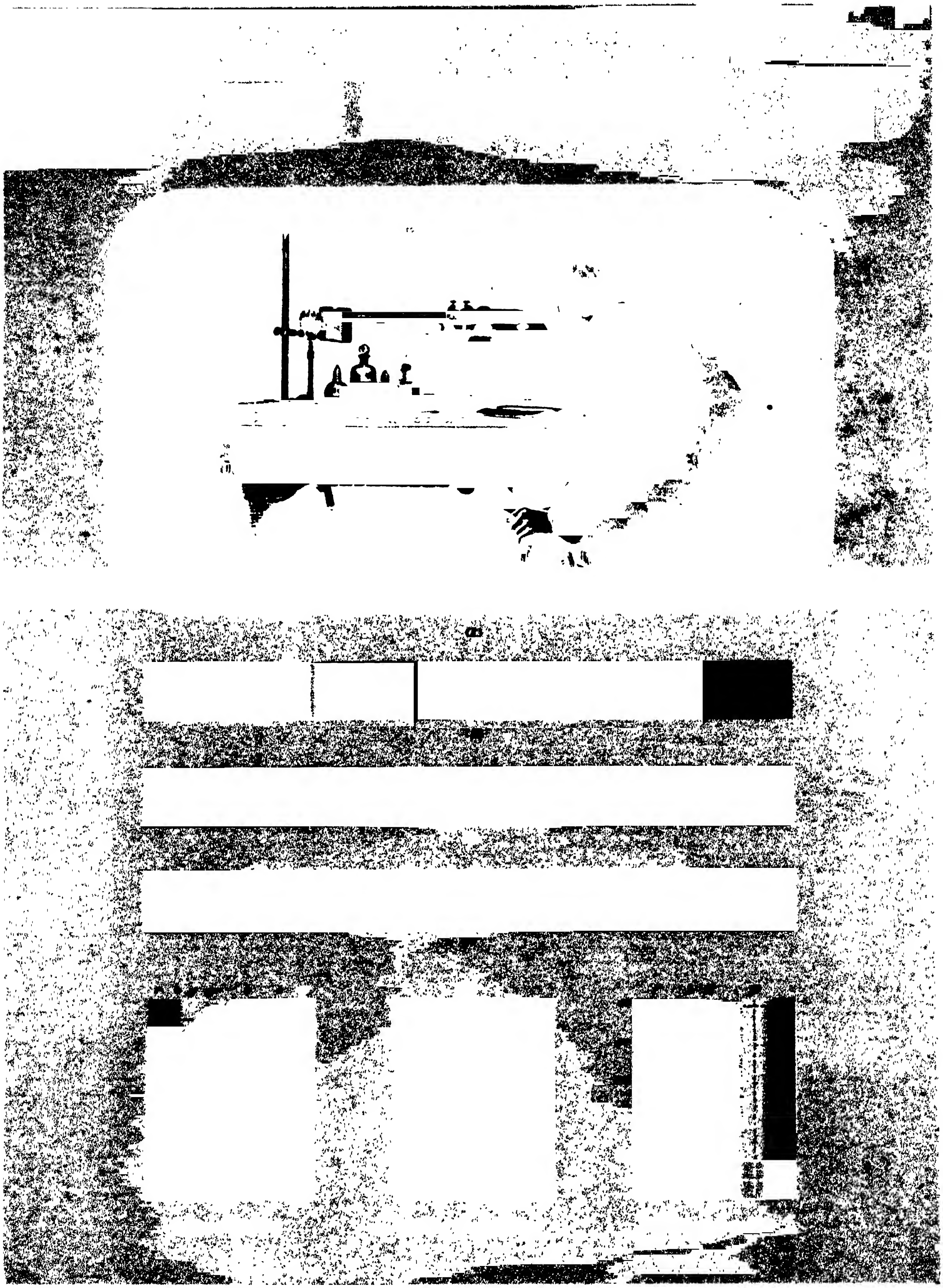

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THE SPECTROSCOPE.

SCIENCE FOR ALL.

EDITED BY

ROBERT BROWN, M.A., PH.D., F.L.S., F.R.G.S.,

AUTHOR OF "COUNTRIES OF THE WORLD," "PEOPLES OF THE WORLD," ETC

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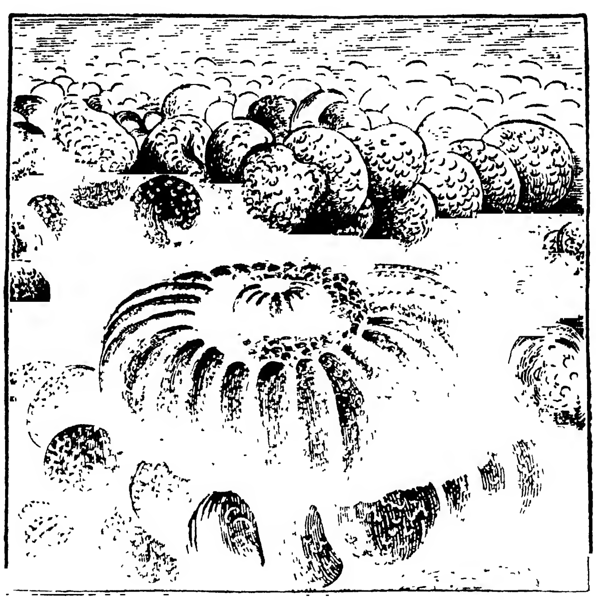
CONTENTS.

CADDIS FLY (*Phryganea striata.*)

LIST OF ILLUSTRATIONS.



MELON-SHAPED CONCRETIONS FORMED BY THE TURBAN GEYSER, UPPER YELLOWSTONE RIVER, UNITED STATES.

SCIENCE FOR ALL.

AN ECLIPSE OF THE MOON.

By Professor Simon Newcomb, LL.D., F.R.S., Washington, D.C.

LONG before the time when the celestial motions began to be carefully studied, it must have been noticed that on certain occasions the full moon wholly or partly faded away for a period of several hours. When it was supposed that extraordinary celestial phenomena presaged great events in the history of nations, rulers looked upon such occurrences with gloomy forebodings, and caused them to be recorded in the public chronicles. The sentiment thus inspired is graphically described by Milton:—

> "Like the moon, whose orb
> In dim eclipse disastrous twilight sheds
> On half the nations, and with fear of change
> Perplexes monarchs."

Before the dawn of history it was remarked by observant men that these alarming occurrences were never seen except at the time of full moon. This general fact once established, it required no power of insight beyond that of the ancients to divine the cause. The earliest astronomers concluded, on various grounds, that the earth was round, and that the distances of the heavenly bodies vastly exceeded the dimensions of the earth itself. The waxing and waning of the moon made it clear that that body, like the earth, was a dark one, shining by the reflected light of the sun. Since all dark bodies in the light of the sun cast a shadow, the earth must do the same thing; indeed, the darkness of night is simply the shadow of the earth.* Hence, if the moon ever enters this shadow, her light must fade away. Since this can happen only when she is in the opposite direction from the sun, it would be only at full moon that such an event could happen. As all records showed that the "darkenings" of the moon, indicated by the Greek word *eclipse*, had occurred only at full moon, the conclusion that they were caused in this way became inevitable. The question why there was not an eclipse at every full moon was readily answered by showing that the moon might pass above or below the shadow, instead of going through it. Observations which could be made without instruments demonstrated that she did not always follow the same path round the earth, and that it was only at considerable intervals that she could really enter the shadow. Thus the extraordinary occurrences were explained in a manner which should have made it clear that the destiny of monarchs was in no way affected by them.

But it is one of the curiosities of human nature, which we find exhibited even in our own time, that ceremonial observances are continued long after the ideas from which they originated have passed away. The form of delivering the sun or moon from an eclipse by propitiatory acts was rigidly adhered to in China many centuries after it became possible to predict the occurrence; indeed, we are not certain but that some relics of the custom still survive. When an eclipse was to occur it was the duty of the imperial astronomer to apprise the emperor of its approach, and of its probable magnitude, five months in advance. A decree was then to be issued by the emperor, announcing the coming event throughout his dominions. When the eclipse actually commenced, pieces of silk were attached to the doors of the ministers of ceremonies, and incense was burned in the great hall of the palace. Music and the beating of drums were continued during the whole period that the eclipse remained visible. The nobles offered up prayers on their knees, striking the ground with their foreheads. In these relics of an ancient custom we may see what alarm was caused by these phenomena before their cause was revealed by scientific investigation.

The great fear which eclipses inspired had the good effect of causing them to be carefully recorded for the benefit of posterity, who were enabled to add the observations of their predecessors to their own, and thus obtain richer material for investigating the celestial motions. An inadequate idea

* See "Science for All," Vol. I., pp. 1, 90, 95, 162, 204, 205, 224; Vol. II., pp. 78 -- 81 (Eclipses of the Sun), 113; Vol. III., pp. 143, 169, 346; Vol. IV., p. 9.

of the astronomical knowledge of the ancients is very generally entertained in our own times, and is nurtured by the depreciatory remarks which modern writers are too apt to apply to the ancient systems of astronomy. It is supposed that the Spanish Jesuits combated the opinion that the earth was a sphere when Columbus proposed his great voyage, and that in arguing thus they were only giving expression to opinions which had always been entertained. In fact, however, before the Christian era the Greek and Egyptian philosophers knew more about eclipses and the motions of the moon than a large majority of the men of average education at the present day.

If Ptolemy had been told that during the first half of the nineteenth century the accuracy of his astronomical knowledge would be a subject of discussion among learned men in distant regions of the earth, and asked to prove his powers by predicting the eclipses of the moon which would happen during that period, he would, after long calculations from his tables, have been able to predict, within two or three hours of the truth, the occurrence of every considerable eclipse of the moon from 1800 until the present time, and, indeed, for many centuries to come. His only serious error would have been that we should have found his prediction two or three hours late. For instance, on the morning of June 12, 1881, there was a total eclipse of the moon at two o'clock in the morning, Washington time, which corresponds to nine o'clock on the meridian of Alexandria, where Ptolemy made his observations. The time given by Ptolemy would have been quite correct, except that he would have assigned noon of June 12th as the date of the eclipse. He would generally have predicted with correctness whether each eclipse would be total or partial, and, indeed, could have made a fairly correct family almanack for any year whatever.

To the casual observer eclipses of the moon, as well as of the sun, appear to occur at very irregular intervals. These intervals are determined by a combination of very beautiful and simple laws of the celestial motions, which the reader will be able to comprehend by a little close attention, combined with some exercise of the imagination. Look up at the sky. Imagine it to be a great vault 240,000 miles away from us in every direction, which it is well known is about the average distance of the moon. The sun is shining upon the earth, and from the latter a shadow will be thrown upon this vault. If there were a real solid arch of the firmament at that distance, this shadow would every night be distinctly seen upon it as a black disc some three times the apparent size of the moon. It would rise regularly at sunset and set at sunrise. As the stars rise and set, this round shadow would rise and set with them. But, watching it from night to night, we should find it to have a slow motion among the stars. The earth moving around the sun in its annual circuit, this shadow will in the same length of time move around on the celestial vault among the stars, completing a circle at the end of the year. Suppose the centre of the shadow to be a pencil-point making its mark as it moves around. Then at the end of the year the pencil-point would have marked out a complete circle upon the hollow vault. Supposing these stars set in the vault, this circle would be visible amongst them. It would pass very near the stars Aldebaran, Regulus, and Antares. To the eye of the astronomer the apparent position of this imaginary circle is as well defined as if it were a visible object. It is called the *ecliptic*.

We all know that the moon describes a similar circuit in the heavens every month. Suppose that she also marks out her path upon the vault as she moves around. This path would also be a circle like the ecliptic. These two circles would be very near, but not quite together. They would cross each other at two opposite points (Fig. 1) on the vault, and be at their greatest distance, of five

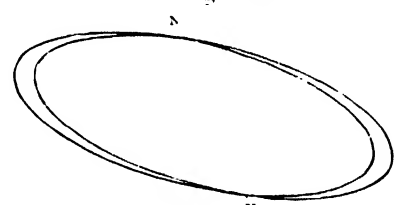


Fig. 1.—The Ecliptic and the Moon's Path around the Celestial Vault. The Moon moves in one circle, the shadow of the Earth in the other. N N, the Nodes of the Moon's Orbit.

degrees, or ten diameters of the moon, half way between these points.

The two points of crossing are called the *nodes*. At one point the moon crosses to the north of the ecliptic. This is called the ascending node. At the opposite point she crosses to the south. This is called the descending node. The reason of applying these terms, *descending* and *ascending*, is that in the northern hemisphere, where astronomy has been founded, the northern side of the ecliptic appears above the south side.

Now let the reader examine Fig. 2. Here the line A B is supposed to represent a small piece of the ecliptic, and C D a small piece of the moon's

orbit, as marked out on the celestial vault. The node is in the centre of the black shadow-circle G. E, F, and G show three positions of the moon, and three positions of the earth's shadow are seen below. It is now evident that if the shadow is to the left of A the moon will pass entirely above it, and there will be no eclipse. When the shadow is at F the moon will dip deeply into it, but will not be entirely covered. Here, therefore, there will be

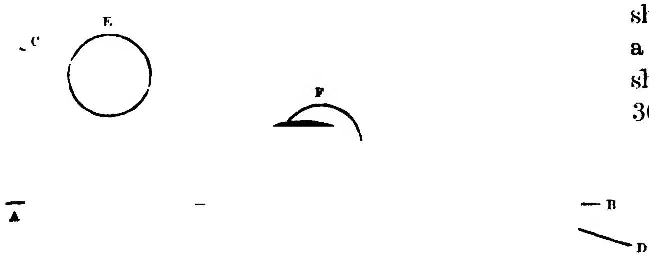


Fig. 2.—Showing how the character of a Lunar Eclipse depends upon the distance of the Shadow from the Node.
(From Chambers' "Handbook of Astronomy," by permission of the Delegates of the Clarendon Press.)

a partial eclipse of the moon. At G the moon will pass centrally through the shadow, and will be totally eclipsed. We thus reach the following conclusions:—

If the earth's shadow is very near the node when the moon crosses it there will be a total eclipse of the moon.

If the shadow is eight or ten degrees away there will be a partial eclipse; that is, the moon will dip partly into the shadow, as at F.

If the shadow is much farther away from the node there will be no eclipse, because the moon will pass above or below it.

Everything, therefore, depends upon the position of the shadow and the node. Because there are two opposite nodes, and the shadow moves around its circuit in the course of the year, it follows that the shadow will cross a node every six months. Hence it is only at intervals of somewhere near six months that an eclipse of the moon can occur. As an example, the shadow of the earth passed the ascending node on June 9th, 1881. This was only three days before the full moon. The latter, therefore, reached the shadow in three days, During that time the shadow moved away so short a distance from the node that there was a total eclipse. Continuing on its course, the shadow reached the descending node on November 30—five days before full moon. During this time the shadow got so far from the node that the moon did not pass entirely through it, and there was a partial eclipse.

Now, if the nodes always retained the same position on the celestial vault, eclipses of the moon could occur only about the dates we have mentioned, namely, between the 1st and the 25th of June, and during the latter part of November or the first part of December of every year.

But now an additional movement sets in. The nodes do not always retain the same position, but continually move from east towards west. To understand this motion we look at Fig. 3, in which the horizontal line from east to west is supposed to represent the ecliptic. The lower dotted line is a small portion of the moon's orbit, and the circles 1, 2, 3, &c., to 10, represent ten successive positions of the moon in her monthly course. In position 9 she is exactly at the node.

Now wait a month, and look at her again as she crosses the same point. She will no longer pass along the line *a a*, but along *b b*, and the node will be near the figure 7. At the end of another month her course will be along *c c*; at the end of the third month along *d d*; at the end of the fourth

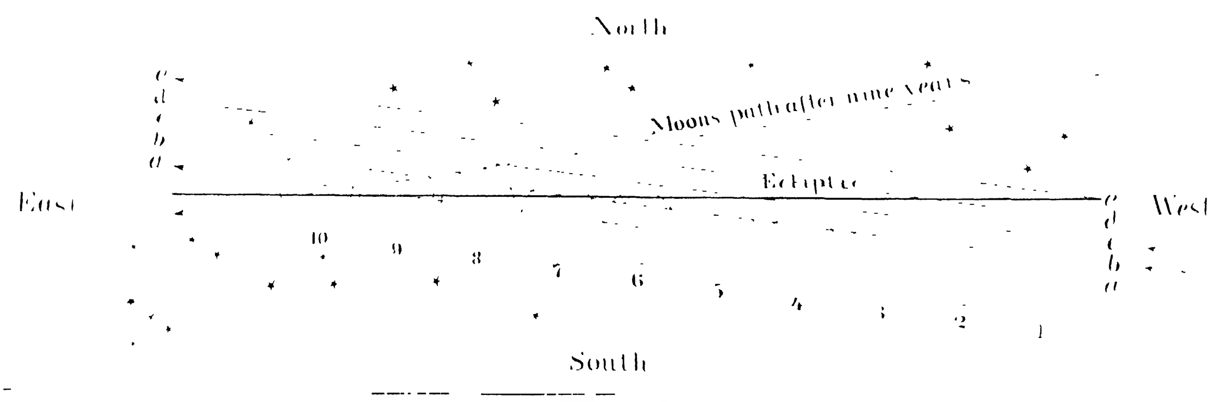


Fig. 3.—Showing Continuous Motion of Moon's Node toward the West.

month along *e e*. Then the node will have moved to the right hand end of the figure. Continuing this change for nine years, or more than 100 revolutions of the moon, the node will have moved half way around the heavens, and the opposite node will have come into the same position in which the first one was when we started. The position of the moon's path at this time is shown in the figure. At the end of eighteen years and six months the nodes will have made a complete revolution, and the moon's orbit will be found in its original position.

This revolution of the moon's nodes has taken place unceasingly since the planets began to revolve in their courses. Seventeen hundred years ago it had been so carefully calculated by Ptolemy that, as we have just said, he could follow it down all the centuries which have since elapsed. It affords a key to the mysterious numbers which connect the intervals between eclipses.

Now observe the consequence. The motion of the node itself is from east towards west, while the shadow, the earth, and the moon all move in an opposite direction, so that the node continually moves along to meet the shadow. The result is that it does not take quite six months for the shadow to pass from one node to the other, but about ten days less than six months. Consequently, the period when eclipses may occur is about twenty days earlier every year. In a little more than eighteen years, this makes up an entire year; and thus the *eclipse season*, as we may call it, returns to its original position. Consequently, if we start from any day when the earth's shadow is passing through the node and count forward periods of six months less ten days, we shall for a long time hit very near the times when eclipses of the moon can occur. The intervals may vary by two or three days owing to the earth's motion around the sun not being uniform; but we need not trouble ourselves at present with these little deviations. The main point to be understood may be put in a more precise shape, as follows—

On June 27th, 1880, the earth's shadow crossed the ascending node of the moon's orbit.

On December 18th of the same year it crossed the descending node.

On June 8th, 1881, it crossed the ascending node again.

On November 30th, 1881, it crossed the descending node again.

On May 20th, 1882, it once more crossed the ascending node; and will so continue as long as the celestial motions shall go on without disturbance according to their present laws.

Eleven or twelve days before, and eleven or twelve days after, each of these dates, the earth's shadow will be so far from the node that the moon will pass either above or below it; so that eclipses can occur only within eleven or twelve days of the dates given above.

The reader will, of course, understand that these dates have no reference to the position of the moon herself, but only to the position of her orbit, which we have supposed to be pencilled out on the celestial vault, and of the earth's shadow. If there does not happen to be any full moon within eleven or twelve days of the dates which we have mentioned, there can be no eclipse. This will often happen, because the period between two full moons is twenty-nine and-a-half days. For instance, a full moon will occur on the 1st of June, 1882, twelve days after the passage of the node. Consequently there will be no eclipse at that time, although the moon will very nearly touch the shadow. Sometimes, therefore, there will be a whole year during which there will be no eclipse of the moon at all, and there can never be more than one at each interval of five months twenty days.

There is another very remarkable cycle frequently referred to, called the *Saros*, which was discovered by the most ancient astronomers. We have said that the times of eclipses were carefully recorded in ancient times among the historical annals. Thus each generation had the eclipses noticed by its predecessors, during periods of perhaps many centuries, to study and to compare with its own observations. When the power of predicting an eclipse was something very wonderful, which would gain its possessor the highest consideration in the royal court, it was very natural that the priests, soothsayers, and astronomers should study the records of their predecessors with great care, in order to see if they could not find some law by which they could foresee eclipses in the future. By such studies, combined with some knowledge of the moon's motions, it was found that all important eclipses repeated themselves at intervals of eighteen years and eleven days. Suppose, for instance, that there should be an eclipse of the moon on January 1st, 1880. There would then be another eclipse of about the same magnitude on January 12th, 1898, a third on January 23rd, 1916, and so on forty or fifty times in succession. Hence, with a careful record of the eclipses through eighteen years, it was possible to predict those to come during the next

eighteen years by this simple process. The same method would be equally applicable at the present time if there were any occasion to make use of it. For instance, a total eclipse of the moon which occurred June 1st, 1863, would be repeated on June 12th, 1881. But as these phenomena are calculated from exact astronomical data in all our almanacks, there is no need of making use of the period.

It is not certain whether those who first discovered this period had a clear idea of the connection among the motions of the sun, moon, and node which causes it. This connection is, however, so simple that it was discovered before the time of the earliest astronomers whose writings have come down to us, and can be understood even by an unscientific reader with a little thought. We have just described the period of five months twenty days between two eclipse seasons, two of which periods make about eleven months and twelve days, and measure the time required for the earth's shadow to go around the heavens from one node and reach the same node again. To use more exact numbers, the average time required to perform this revolution is 346·6201 days. Nineteen of these periods will make 6585·780 days.

Now let us return to the moon. The average interval between two full moons is 29·530588 days. Multiply this interval by 223, and we shall have 6585·32 days. That is, 223 intervals between successive full moons make a period of time which is only half a day less than the time of nineteen returns of the shadow to the node.

Now let us see the consequence of this. On June 1st, 1863, at six o'clock in the evening, the moon was immersed in the earth's shadow, and both were six degrees past the ascending node. Since that time the shadow has made a number of revolutions, and there have been more than 200 full moons. But in none of these full moons has the moon been in the shadow exactly 6° from the node. But if we reckon forward 6585·32 days, the moon will be again in the shadow at almost this exact distance from the node, because both the moon and the shadow will have made an exact number of revolutions. Since, as previously explained, the magnitude of the eclipse depends upon the distance of the shadow from the node when the moon passes through it, it follows that at the end of the period the eclipse will be of a magnitude similar to its predecessor of eighteen years before. The date of this repetition of the eclipse is that already given—June 12th, 1881.

There is but one drawback to the use of this period. It consists of a round number of days, and about one-third of a day; that is, eight hours over. Consequently the eclipse will not recur at the same hour of the day, but will be eight hours later. Hence it may not be visible at the same points of the earth's surface. In fact, in the majority of cases, the moon will have set at the points where the eclipse was previously visible. If the first eclipse occurred at nine o'clock in the evening, the next one would indeed be visible, because it would occur at five in the morning. But if the first one occurred at midnight, or later, its successor would not occur until the sun had risen, and the moon had set. Still, it is very easy, after one has got the period once in mind, to make allowance for this fraction of a day over, and thus to predict whether the eclipse will or will not be visible at the previous place of observation.

What takes place during an eclipse of the moon can be understood by comparing figures 4 and 5. Fig. 4 shows the form and situation of the shadow and penumbra cast by the earth. The penumbra is that region where the light of the sun is partly cut off by the earth. Its outlines are found by drawing straight lines from each edge of the sun through the opposite edges of the earth. The shadow is the region where the sunlight is all cut off. Its outlines are formed by drawing lines from the edges of the sun, so as to touch the earth on the same side.

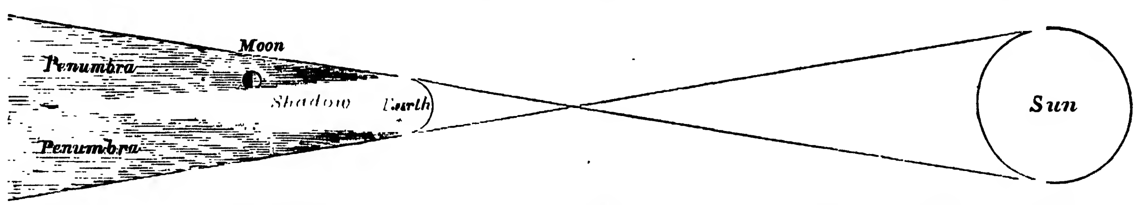


Fig. 4.—Form of the Earth's Shadow; the Moon just leaving it. Within the Shadow the Moon is nearly invisible; within the Penumbra it is visible.

To understand fully the form of the shadow and penumbra, we study their cross-section at the distance of the moon shown in Fig. 5.

Supposing, as we have already done, that the celestial vault is as far as the moon, the observer might see the shadow thrown upon the vault.

Fig. 5 shows this appearance as it would be, were the vault really there. Of course, the shadow, as we have marked it out, is not really visible, the whole sky being involved in a darkness. But if we could see the shadow just as it is where the moon enters, it will present the appearance shown in the figure.

The phases of a total eclipse of the moon, as laid down in our almanacks, are seven in number. The first phase, marked 1 in the diagram, is that when the moon first touches the penumbra. The time of the moon reaching this point is that first given in the almanack. About the hour following, the moon passes from the position 1 to the position 2. It is, however, remarkable that during this time the observer can really see scarcely anything of the coming darkness. Although one-half, three-quarters, or nine-tenths of the light of the sun is cut off from the moon, he would scarcely notice that the moon shone less brightly than usual. This is a result of the capacity of the eye to be subject to great variations of light without a corresponding change in the sensation. It is hard to conceive, as one looks up at the full moon, shining brilliantly in the sky, that her light is only $\frac{1}{600,000}$ part of that of sunlight. If on some night the moon should give ten times as much light as usual, people might remark how brightly the moon was shining, but the difference would not be at all striking. Hence it is not remarkable that, with the light of the moon diminished to one-tenth, she still looks very much as she generally does.

The difficulty of seeing any change is increased by the fact that there is no other moon of full brightness to compare her with. If, when the light is only half cut off, we had another moon of full brightness to compare with, the eye could then see the difference. But without such a help the observer notices nothing until the moon almost reaches the position 2. Then he sees a curious darkness on the edge of the moon at the point *a*. The appearance is much as if some dark-brown substance were rubbed over it. The time when the darkness first begins at the point *a* is given in the almanack as that when "moon enters shadow."

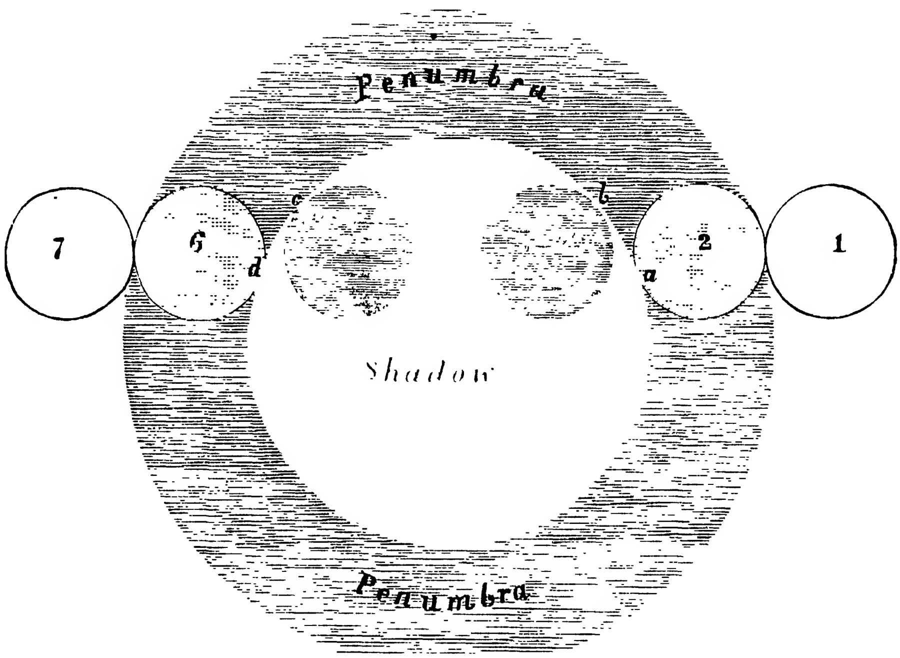


Fig. 5.—Cross Section of the Earth's Shadow where the Moon passes through it.

Principal Phases of a Total Eclipse of the Moon—1, Moon enters Penumbra; 2, Moon enters Shadow, touching at *a*; 3, Total Eclipse begins, *b* being the last part of the Moon which enters the Shadow; 4, Middle of Eclipse (not marked); 5, Total Eclipse ends, Moon coming out at *c*, 6, Moon leaves Shadow, *d* being the last part to leave; 7, Moon leaves Penumbra.

As the moon passes from position 2 to position 3, more and more of her body is immersed in the shadow. At first the dark portion is totally lost to view. When only half the moon is visible, the remaining half appears as if the old legend were true, and some celestial dragon were eating up our satellite. But when she has almost entirely entered, the portion of her disc which is in the shadow gradually comes into view as an indistinct reddish surface. The reason this red light is not seen before is, that it is overpowered by the full brilliancy of the moon. When the latter is entirely in the shadow she is, for the most part, distinctly visible, shining as she does in this reddish light.

The fact that the moon is not wholly darkened is due to the action of the earth's atmosphere upon light passing through it. It is an optical law that when a ray of light passes obliquely through a transparent medium it is bent out of its course. The atmosphere of the earth exercises such an effect in this way that, when the setting sun has just reached the horizon the real sun has sunk wholly below it. We may be said, in a certain sense, to see the sun around a corner. The result of this action upon the rays of light coming from the sun is, that all such rays as pass close to the earth's surface are bent around, so as to continue on their course into the shadow itself, and thus meet the moon. In consequence, however, of the blue rays being absorbed by the atmosphere, only the red rays pass through. Every one knows that the setting sun looks red, and it is these rays alone which can reach the moon during the eclipse; hence it is that we see this faint light shed upon her.

It must always happen that more or less of the light which might thus reach the moon is cut off by clouds in the earth's atmosphere. If it should happen that around all those regions of the earth where the sun was rising or setting, cloudy or rainy weather prevailed, it might chance that scarcely any light could reach the moon. It is believed that observation agrees with this conclusion, and that the moon is seen much more plainly in some eclipses than in others. Indeed, it is on record that the moon has sometimes totally disappeared during an eclipse.

Kepler says that, in the year 1601, when the moon was entirely eclipsed, except a very small portion near one edge, the eclipsed part entirely disappeared. He mentions another instance, in 1620, when during a total eclipse not a trace of the moon could be distinguished, although the stars shining around her remained distinctly visible, showing that the air was clear. Hevelius says that he observed the same thing in 1642. It is a little curious that such cases have not been remarked in recent times. It is, however, certain, even from recent observations, that there are great variations in the light of the moon during different total eclipses. The Rev. Charles Mayne, in a communication to the Royal Astronomical Society of London, stated that during the lunar eclipse of March 19th, 1848, one of his family, going to the window, exclaimed, "The eclipse is over." Going to look himself, he saw that the moon was of the colour of tarnished copper, and was therefore still totally eclipsed. That the luminosity of the moon was remarkable during this eclipse is shown also by the evidence of other observers. The British Consul at Ghent, who did not know that there was an eclipse, wrote to a scientific friend to ask an explanation of the blood-red colour of the moon on that evening. Mr. Walkey, who observed the same eclipse in England, describes the moon as most beautifully illuminated, and assuming the appearance of the glowing heat of fire from a furnace tinged with a deep red. The whole disc of the moon was as perfect with light as if there had been no eclipse whatever.

We are thus led to the curious conclusion, that we can form an idea of the weather around a certain zone of the earth by the appearance of the moon during a total eclipse. If the moon looks bright, the weather is fine where the sun is, at the time, rising or setting. If she looks dark or disappears entirely, the weather is stormy. The observer, however, will not generally be in the zone where the weather is indicated by the eclipse.

Sir George Airy attempted to make an exact determination of the amount of light given by the moon during the eclipse of June 1st, 1863. His result was, that about as much light was received from the whole surface of the moon as from a star of the first magnitude. The difference of colour would, however, render it difficult to make a comparison like this with precision.

One curious appearance, which has sometimes been remarked during a total eclipse, is that of the brightness of one of the lunar spots, *Aristarchus.* This is such that in Herschel's time there was supposed to be a volcano in active eruption at this point. The appearance which gave rise to this deception can be seen, even without a total eclipse, by observing the moon with a telescope, through a very clear air, when she is about three days old, choosing a time near the end of twilight. It is now believed to be due to the extreme whiteness of this spot, throwing back towards the earth a large portion of the light which falls upon it from the earth.

The fourth phase given in the almanack is that of the middle of the eclipse. There is no need of marking it in the figure.

The fifth phase is that when the total eclipse ends and the moon begins to emerge into sunlight at *c*. Although on first coming out she does not get the tenth part of full sunlight, being still in the penumbra, she looks as bright as ever. Gradually the whole disc comes out, and to all appearance she is fully restored immediately after the last edge of the shadow has passed away from *d*. This is the sixth phase given in the almanack, and then for all

practical purposes the eclipse is over. The seventh phase is, however, calculated with conscientious precision, though no one is ever able to observe it.

Whenever we see an eclipse of the moon, there would of course be an eclipse of the sun to an inhabitant of the moon. It will be interesting to notice the relations between what we see on the moon, and what an observer on the moon would see on looking up at the earth and sun.

When the lunar observer first entered the earth's penumbra, he would see the edge of the earth begin to cut off a portion of the sun. When in the middle of the penumbra, the sun would be half cut off. The appearance which would then be presented

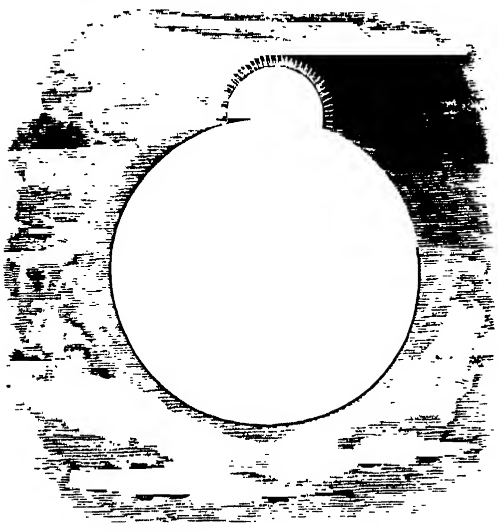


Fig. 6.—Partial Eclipse of the Sun by the Earth, as seen from the Moon.

to him is shown in Fig. 6: one half the sun is shining with full brilliancy, the other half is behind the earth.

The latter is itself almost entirely invisible, though it might be dimly seen shining with a very faint light against the dark background of the sky. The sun, it will be noticed, is but little more than one-fourth the apparent diameter of the earth as seen from the moon, his vastly greater magnitude being more than counterbalanced by his greater distance. After the sun had completely disappeared behind the earth, the outline of the latter would be distinctly seen by a red light refracted by the atmosphere in the manner already described. The surface of the earth itself would probably be entirely invisible, and nothing but this red ring of light, broken here and there by clouds, would be seen. The sun would, in fact, be totally eclipsed for a length of time vastly greater than he is ever eclipsed to an inhabitant of the earth.

One of the most important services which have been rendered by eclipses is that of enabling us to fix the dates of ancient historical events. It is possible, with our accurate tables of the moon's motions, to calculate every eclipse which has occurred during the past three thousand years, giving the true time within an hour, and thus ascertaining where the phenomenon was visible. It can be determined with equal certainty whether the eclipse was total or partial. Hence, if an eclipse is associated with any occurrence, it is only necessary to be able to identify it, when the date of the occurrence will be accurately determined. Ptolemy cites a great number of lunar eclipses in which he gives the name of the reigning monarch at the place where observed, and thus fixes with precision a number of points in Grecian and Babylonian chronology.

This use of eclipses is intimately associated with their application to determine the motion of the moon. The accurate ideas of this motion which we have already described, were gained by the ancient astronomers principally from observations of lunar eclipses. The fact that these eclipses occurred only near the node, always enabled them to fix the position of the node, within a few degrees, when the eclipse was visible. If the eclipse were a partial one, the node would be determined with still greater accuracy, because, knowing the magnitude of the eclipse, it was possible to calculate how far the node was away, in order that just so much of the moon should be immersed in the earth's shadow. The time of the moon's revolution was determined by the interval between the middle of important eclipses several centuries apart. In modern times eclipses of the moon were used in the same way, and thus enabled Halley, a century and a half ago, to show that the moon's motion had been accelerated since the ancient observations. But we have now so many more accurate methods of determining the moon's position, that lunar eclipses are no longer used for this purpose. Indeed, they have ceased to be occurrences of great interest to the professional astronomer, because he knows as much about an eclipse before it begins as he can observe during its occurrence. The only uncertain element is the brightness of the moon. But such occurrences can never cease to be of interest to the public, even if they do nothing more than give a visible assurance that the celestial motions are continuing without the slightest disturbance, and that astronomers still possess the power of predicting them with entire certainty.

COLOUR.

By William Ackroyd, F.I.C., etc.

It is related of the celebrated Greek artist Zeuxis, that he painted grapes so well that birds flew at his picture to eat the fruit; and of his rival Parrhasius, that he deceived Zeuxis himself by the remarkable manner in which he portrayed a curtain. A clever colourist of the present day can also accomplish some wonderful things, as our art exhibitions regularly prove, so that we have had from the remotest times a surprising command of colour for imitative purposes. Now, it is highly probable that among the early painters, and indeed, among other men, the question would often suggest itself as to how or why colour is produced in nature—why the rainbow has such resplendent hues, and the flowers of the field such varied tints, and any original thinker among them untrammelled by the ideas then in vogue, would have concluded upon a careful view of the matter, that the doors of a mine of knowledge were closed against him. Such remained the case until the advent of Newton, who here, as in many other instances, pronounced the magical "Open Sesame."

When Newton ascertained respecting a sunbeam that it consists, roughly speaking, of the seven different kinds of light which one sees in a rainbow, he had discovered the fundamental fact underlying the various phenomena of colour. The colour of most substances could now be explained. We will suppose you are looking at a bunch of strawberries under its heavy roof of leaves, a rosy cheek on each berry being turned towards the sun. To what is its colour due? Now since the skin of the berry appears red – *i.e.*, the principal light reflected from it is red—it is apparent that the remainder of the white light has been kept back and drunk in or absorbed by the surface. The skin of the berry has selected certain rays for absorption, and refused the others, which have accordingly been reflected. This is the modern doctrine of *selective absorption.* A sheet of white paper is white because all the seven kinds of light are reflected from its surface; a lily is white for the same reason, but many a yellow petal is yellow because, when white light falls on it the violet, indigo, blue and green rays are selected for absorption, and yellow principally is reflected. The reflected rays are received by the eye, and produce the sensation of colour. An explanation of this sort will do for a host of colours, in fact for nearly all the colours that exist. Two exceptions have been already dealt with; the colours of the rainbow, which are due to rain-drops acting on sunlight like glass lustres,* and the colours of soap bubbles, which are caused by the destruction of part of the white light which falls on them, owing to the mingling of the beams reflected from the first and second surfaces of the film of soap solution.†

It will be observed that these colours we have spoken about have an objective reality, for they are the result of certain changes produced in white light by external objects. One sees, however, sometimes, *subjective* colours, *i.e.*, colours which are due more to a particular condition of the eye than to a state of external things. This arises from the eye becoming colour-wearied under certain circumstances. Thus, you may gaze at the red embers of the house fire until the eyes become wearied of the particular light the embers emit. If a surface of white paper be now looked at, the eye is only able to distinguish well those portions of the reflected light which are not like the rays emitted by the red hot cinders. As one therefore looks at the paper, a purplish image of the fire appears on it. The colour of this subjective image is said to be *complementary* to the reddish light of the fire.

The moon sends us the white light of the sun, it is a sort of vast looking-glass suspended in space, which diverts the solar rays and sends them here at certain times when we are in darkness. Its white or silvery lustre is proverbial, so that if one could weary the eyes for any particular colour, the moon ought, like the white paper, to appear of the complementary colour upon turning the wearied eyes towards it. Under such circumstances the writer once saw a blue moon. He had been gazing for a full half-hour at the orange-red light of a burning building, and upon transferring his gaze to the surface of the moon, it was of a decided blue. And from other experiments, one may assert, that if the light of the burning building had been of any of the colours given in the first column which follows, the moon would have appeared of the complementary colour, given in the second column:—

Colour.	Complementary.
Red	Bluish-green.
Orange	Blue.

* "The Rainbow:" "Science for All," Vol. I., p. 194

† "Iridescent Glass:" "Science for All," Vol. I., p. 361.

Colour.	Complementary.
Yellow	Indigo.
Green	Reddish-violet.
Blue	Orange-red.
Indigo	Orange-yellow.
Violet	Yellow.

Some such phenomenon as the preceding happens when one has been for a while in a building illuminated by the electric light. This light is particularly rich in violet, indigo, and blue rays, while ordinary gas-light is quite poor in them. Hence, when one has been with the electric light for a while and the eye has become wearied of its blue, indigo, and violet rays, any weak light like that of a gas-lamp appears of the complementary colour, so that upon turning out of the place of entertainment or business where the electric light is, into the lamp-lit street, the lamp-lights, one and all, appear painfully yellow.

The kind of appearance we have been speaking about may be produced artificially in the following way. Suppose A (Fig. 1) to be a red circle (you can easily paint a circle red, or cut a circle out of a piece of red paper for the experiment); look steadily at the centre of it for about thirty seconds in a strong light, and then turn your attention to the centre of the white circle (B) by the side of it. The latter will now appear of a complementary colour to the former—viz., of a pale bluish-green.

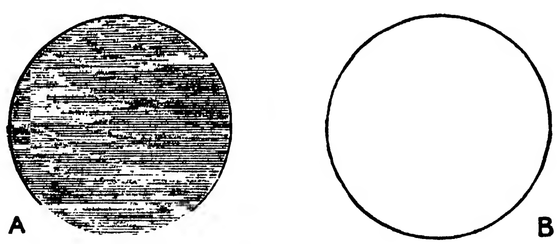


Fig. 1.—How to see a Complementary Colour.

If a combination of all the colours in the first column, *i.e.*, white, be steadily stared at, then since the eye has become wearied for all of them together black ought to be seen under proper conditions. In Fig. 2, certain white letters are seen on a black ground; gaze at these steadily for some time in a good light, and then look at the white square. The white letters will now appear black on a white ground. It is no doubt owing to some such cause as this that travellers in the Arctic regions are often troubled with snow-blindness, a total weariness of the sight, brought on by gazing too long at the white glistening snow.

We must now try and ascertain a little more about objective colour, and to this end it will be well for us not only to speak of the appearances which may be seen, but also of the ways adopted for seeing them. In order to analyse a colour, and thus get, as it were, at its individuality, it is necessary to employ the spectroscope. The method of proceeding will be apparent from a consideration

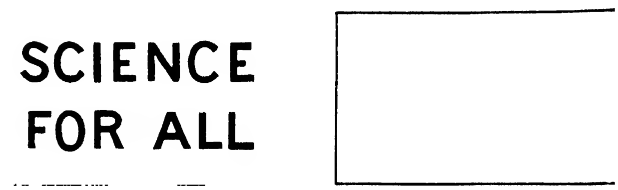


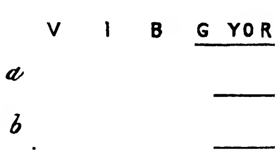
Fig. 2.—White made Black.

of the following example: We will suppose that the reader is sat down before this instrument, with the intention of examining a coloured solution (1).* He has previously taken a particle of solid magenta, of a greenish metallic lustre (3), and dissolved it in methylated spirits highly diluted with water. The solution is placed in a vessel with parallel glass sides, so that light can pass straight through it. If a gas flame be now arranged on one side, and the slit of the spectroscope on the other side of the cell, so as to receive the light which has passed through the coloured solution, the appearance observed will be that given in (2). The colour of the solution, as seen with the unaided eye, is presented in the square patch (4). Now, the bare flame of the burning gas, viewed with the spectroscope, would give a continuous spectrum, *i.e.*, there would be all the colours of the rainbow in it in uninterrupted succession. It is apparent, therefore, that the light, in passing through the magenta solution, has been robbed to some extent, and where it has been robbed there appears a black band. This band is called an absorption band, and the appearance given in (2) is called the absorption spectrum of magenta. So, in like manner, if one were to take the colouring matter of birds' eggs, of the leaves of trees, or of the coloured petals of flowers, upon getting solutions of them and examining these solutions spectroscopically, in the way just described, definite absorption spectra would be obtained, which in a great many instances would serve to identify the particular substance that was being studied. Experiments of this kind may be very satisfactorily performed by means of a home-made spectroscope, such as that which stands on the table below the large spectroscope (1). The two essential parts in a little instrument of this sort are the collimator

* The numbers in brackets refer to the Frontispiece of this volume.

and the prism. The former is simply a tube with a brass slit at one end and a double convex spectacle glass at the other; while the latter is a piece of glass tubing which has been worn into a wedge-shape and then had plain glass ends cemented on to it, and finally been filled with bisulphide of carbon. The light-source and coloured solution being before the slit, the spectrum of the substance is seen upon looking into the bisulphide prism sufficiently well without the aid of a telescope.

In examining coloured fluids, it soon becomes apparent that the colour depends to some extent upon the thickness of substance through which the light has passed. Thus a very thin layer of treacle is quite yellow, but upon looking into a white pot filled with it, the treacle appears of a very much darker tint. The light has really had to pass through a thickness of treacle, which we may suppose to consist of a great number of thin layers, on its way to the white porcelain from which it is reflected, and again has to pass through the same number of imaginary layers on its way back to the eye. Each layer does its share of absorbing some portions of the white light, so that the dark colour of the pot of treacle is the result of much more absorption than that which gives rise to the yellow colour of a very thin layer of it. The spectroscope shows this conclusively. In Fig. 3, two observations of treacle with the little spectroscope we have just described are given. The upper spectrum, *a*, shows that a very thin layer of treacle absorbs the



violet, indigo, and blue light; while the lower spectrum, *b*, shows the effect produced by double the thickness, viz., an increase in the absorption. There are several ways of representing absorption. One may simply draw the appearance seen in the spectrum, as in *a* and *b* (Fig. 3), or the same facts may be set forth by means of drawings such as *a′*, *b′*, or *a″*, *b″*. A horizontal line here represents the length of the spectrum of white light, and the region absorbed is indicated by dark bands, as in *a′* and *b′*, or by curves, as in *a″*, *b″*. As the absorption band in the spectrum decreases in intensity, the dark band in the diagram representing it is made thinner, and the curve approaches the horizontal line.

Several ways have been devised for showing in a diagram at a glance the increase of absorption with increasing thicknesses of the coloured solution; in other words, the whole progress of the absorption from a very thin layer of coloured liquid to a thick one. To this end Dr. Gladstone employed a wedge-

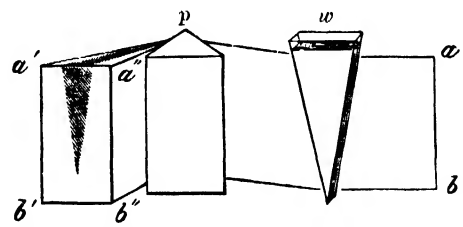


Fig. 4.—Gladstone's Method of seeing the whole Progress of Absorption.

cell of glass, *w*, for holding his solutions. A thin slice of light, *a*, *b*, from a perpendicular slit, was passed through the wedge-cell resting on its edge; and now, upon examining the transmitted light with a prism, *p*, held so that its refracting edge was parallel to the slit, as in the ordinary spectroscope, the complete absorption spectrum of the substance *a′*, *a″*, *b′*, *b″*, was seen. Chromic chloride examined in this way gave somewhat the same figure as (9), where it will be observed that the absorption increases as we pass from the edge of the wedge towards its thicker parts. Müller had previously obtained the full absorption spectra of many substances, although unknown to Dr. Gladstone. His drawing of the absorption produced by a solution of indigo is given in (8). The writer some years ago attempted to place the method on a quantitative basis by using solutions of known strength, and employing thicknesses of from one to fifty centimetres. A quantitative observation is given in (10), and such a diagram is meant to convey the knowledge, among other things, that in a solution containing ·0000008 of a gram of magenta per cubic centimetre, a thickness of 10 centimetres produces a certain effect, and the observations with 20, 30, and 40 centimetres show how the absorption increases.

Although, as a rule, a substance when dissolved is of the same colour as in the solid state, there are noted exceptions. Magenta, for example, in the solid state, has a greenish metallic lustre (3), while in solution it is of quite another colour (4). This may be seen very well by making a concentrated solution of magenta in alcohol, and pouring it over a plate of clean glass. When dry, the magenta appears of its peculiar green colour by reflection and of a deep pink when viewed by transmitted

light. Many of the aniline dyes also exhibit this peculiarity, and it would likewise seem to be possessed by the colouring-matter of logwood. Chips of very good logwood display on their edges a yellowish metallic appearance, which, when dissolved off by alcohol, gives a solution differing from it as much in colour as the green and pink of magenta differ. Gold is also another example of the same kind A very thin leaf of the metal, when examined by transmitted light, is greenish, but the ordinary appearance of the gold, that is, its colour by reflection, is yellow. It is a peculiar fact, made out by Stokes and others, that the light reflected from such substances as solid magenta is of the same quality as the light which their solutions absorb.

We have said that the spectrum of white light, like that of a candle, is a continuous one with no interruption from the violet at one end to the red at the other. Coloured flames give a widely different kind of spectrum. If a platinum wire which has been dipped into a solution of common salt be inserted into the colourless flame of a Bunsen burner, a golden-yellow light is obtained. An examination of the flame with a small spectroscope shows only a single yellow line of light (5), which may be resolved into a couple of yellow lines with a more powerful instrument. The metal sodium, which is contained in common salt has therefore a very distinctive spectrum, and by means of it one can detect a very small trace of this metal in any given mixture. Many other metals give very distinctive spectra when the colourless Bunsen flame is coloured by means of their compounds. Hence, when Mr. Crookes, in 1861, in the spectroscopic examination of a peculiar deposit from a sulphuric acid factory, found a fine green line (6) which could not be attributed to any metal then known, the conclusion was irresistible that he had come across a new element. So it was afterwards found, and the new metal was named after its spectrum, *thallium* (from *thallos*, Gr., green). In a similar way Reich and Richter in 1863, by an examination of the zinc-blende of Freiberg, discovered the rare metal indium by means of its spectrum (7).

But to return to the colours of natural bodies. Perhaps the most important point with regard to them is the alteration of colour that may be effected by means of heat and certain reagents. We have already dealt with the changes produced by heat* and it now remains for us to say something about the colour changes that may be effected by means of reagents. To make clear what is meant take the case of iodine. If one dissolves it in alcohol it forms an orange-coloured solution, and its spectrum is not unlike the one for treacle (Fig. 3), as the violet end of the spectrum is absorbed; but if the iodine be dissolved in bisulphide of carbon, the solution is violet-coloured and the spectrum is now of the same sort as the absorption spectrum of magenta, there being one absorption band seen towards the middle of the spectrum. It is therefore apparent that the spectrum of any particular substance depends much upon the nature of the solvent. A neutral solution of litmus of a blue colour changes to red upon adding a few drops of acid, and may again be changed back to blue upon the addition of a little ammonia. Changes of this kind viewed spectroscopically serve to identify substances, for although two substances may have spectra nearly alike under certain circumstances, it is generally found that the changes which may be produced by the addition of various reagents are sufficiently different to determine that they are dissimilar colouring matters. By taking advantage of this fact, Mr. Sorby found in his study of the colours of birds' eggs that all the variety one sees may be

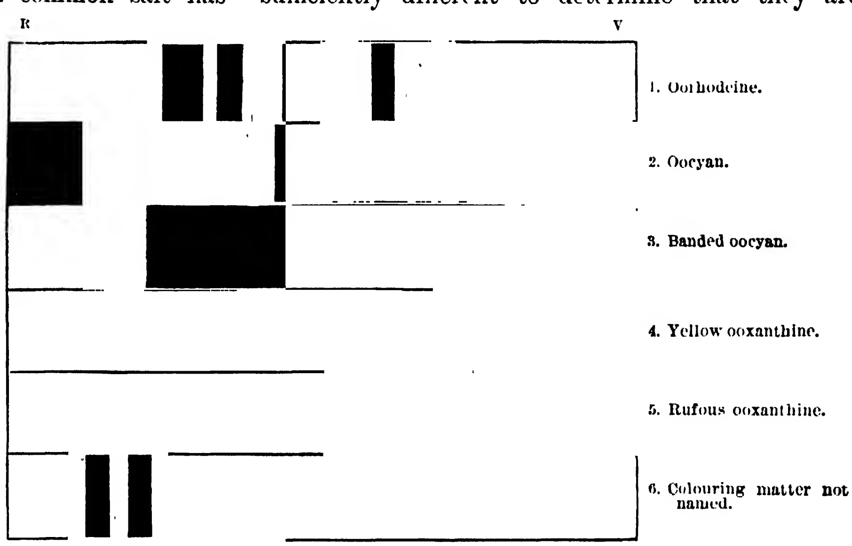


Fig. 5.—Spectra of the Colours of Birds' Eggs.†

* "The Colours of Animals:" "Science for All," Vol. I., p. 256.

† Collected from Mr. Sorby's paper on the Colouring Matter of the Shells of Birds' Eggs, in the "Proceedings of the Zoological Society of London," May 4, 1875.

due to some six or seven colours. They have been christened respectively:—oorhodeine, a red; oocyan, a blue; banded oocyan, another fine blue; yellow ooxanthine; rufous ooxanthine, a colouring matter giving narrow absorption bands in the red; and lichnoxanthine. Their spectra are given in Fig. 5. The nightingale's shell contains a mixture of oorhodeine and oocyan; the blue portions of a thrush's egg are coloured by banded oocyan, while the dark spots contain oorhodeine; and the blue-green of hedge-sparrows' eggs contains a variable mixture of oocyan with yellow ooxanthine. The lichnoxanthine, an orange yellow colour, is found in almost all kinds of plants, but appears to be best obtained from a yellow fungus, the *Clavaria fusiformis* of botanists.

Dr. Thudicum has shown that when the red colouring-matter of blood is decomposed by strong sulphuric acid, a peculiar substance is produced which has been named cruentine. This cruentine bears so strong a resemblance to oorhodeine, that it would seem to foreshadow the discovery of some hidden relation between the red colouring-matter of birds' eggs and the blood itself, which perhaps is not so very improbable, seeing that they are both products of vital phenomena in an animal organism. The oorhodeine dissolved in nearly neutral alcohol gives the spectrum 1, Fig. 5. Imagine each of the five bands to be moved ever so slightly towards the violet end, and then you get the spectrum of cruentine. When these two colouring-matters are dissolved in alcohol with strong acid, they both give a spectrum with three bands which are as nearly coincident as possible, an agreement so close that a superficial observer might conclude that they were absolutely identical.

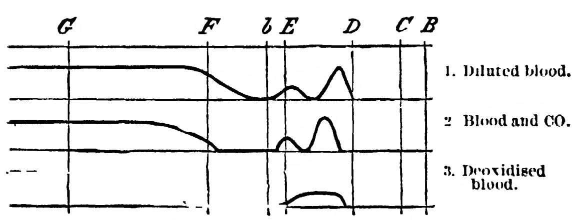


Fig. 6.—Spectra of Blood. (*After H. W. Vogel.*)

The colour of blood itself is an interesting subject of study. Its peculiar spectrum may be readily seen by smearing a glass plate with a drop, and then examining the light transmitted by means of a spectroscope of small dispersion, a one-prism spectroscope, or a direct-vision pocket spectroscope. The spectrum of fresh scarlet blood is given in 1, Fig. 6. When the blood is deoxidised by long standing, or by warming in a water-bath above 50° C., a colour change occurs, and the spectrum now is like 3, Fig. 6. The blood of animals that have died from asphyxia—*i.e.*, a deprivation of air or suffocation—shows the same change. When blood has been poisoned by carbonic oxide gas (CO) it is possible to determine the fact by means of the spectroscope. A direct comparison of the spectrum of the poisoned blood with the spectrum of pure blood will show that in the former the isolated bands have been moved slightly towards the green (Fig. 6).

Very important matters may be sometimes determined by means of these absorption bands. Here is an instance which happened several years ago. A man was found dead in an outhouse attached to a foundry at Port Dundas, Glasgow. No one knew how he had come by his death. It was possible that some foul crime had been committed, or that he had succumbed to natural causes, but there seemed to be no evidence to rest any opinion on at all. The matter was investigated by Dr. Thorpe and Mr. Falconer King, when it appeared very soon that it was a case of foul air poisoning, for when a pigeon was thrown into the room where the man had died, it fell to the floor, fluttered, and apparently died in about fifty seconds. A dog which was similarly treated succumbed in three minutes. When the blood of the dog was examined spectroscopically it exhibited the changes due to the presence of carbonic oxide. The man had evidently been poisoned by breathing carbonic oxide, and it was subsequently found that the gas had access to the room by means of a cracked pipe, which passed by some smouldering cinders under the surface of the adjoining yard.

By means of these absorption bands it is also possible sometimes to detect coloured adulterants. Thus Sorby has shown how one may detect the presence of such substances as logwood, Brazil wood, rhatany root, and the berries of the Virginian Poke (*Phytolacca decandra*) in dark wines. He also found it possible to tell the age, up to six years, of port wine from the cask. The specimen of wine to be tested was divided into two portions, to one of which a quantity of sulphite of soda was added, the other remaining unaltered. The absorption produced by a thickness of one inch of the altered wine was then compared with a lesser thickness of unaltered wine giving the same amount of absorption. The latter thickness furnished a sufficient indication of the age, as the following figures show:—

Age in years.	Altered wine. Inch.		Unaltered wine. Inch.
0	1	equal in absorptive effect to	·22
$1\frac{1}{2}$	1	" "	·63
$2\frac{1}{2}$	1	" "	·70
$3\frac{1}{2}$	1	" "	·73
$4\frac{1}{2}$	1	" "	·75
$5\frac{1}{2}$	1	" "	·765
$6\frac{1}{2}$	1	" "	·78

Sufficient has now been said to prove that the colour of a substance, be it gaseous or liquid, when analysed by means of the spectroscope, may teach students important facts both in pure and applied science. It sometimes happens, however, that a colour may be so weak that an absorption band cannot be seen by ordinary means, although to the unaided eye the substance may have a definite tint, thus showing us that the colour perception of a normal eye is exceedingly keen. Has it always been so?

The various faculties of civilised man are admitted to have reached their high state of development by a series of stages, and to some thinking minds the question has arisen whether our early forefathers may not have had a poorly-developed perception for colour which, in the course of ages, has arrived at its present state of perfection. Hence it has been supposed that our capacity for distinguishing colours has increased even in historical times. The grounds for this belief are mainly philological. For example: according to Geiger, the colour of grass and foliage is never alluded to as a beauty in the Vedas or Zendavesta, though these productions are praised for their other qualities, and blue is described by terms denoting sometimes green, sometimes black. Moreover the colour of the sky is never mentioned in the Bible, the Vedas, the Homeric poems, or the Koran, yellow is often confounded with green, but along with red it was one of the earliest colours to receive a distinct name. Aristotle gives names to three colours in the rainbow, viz., red, yellow, and green, while two centuries earlier Xenophanes had described the rainbow as purple, reddish, and yellow.

Now both Ernst Krause and Grant Allen have shown that much of this ambiguity in the work of the ancients regarding colours is due to a lack or careless use of words, and it may fully accord with the reader's experience. He doubtless remembers a period when he had only a small list of colour names at command, and at that time, although possessing a keen perception for colour, a name was often given to one tint which ought to have been applied to another—*e.g.*, blue for green, or green for blue—and a great many colours were simply indescribable without reference to some common object of a like tint. Such may have been the position of the ancients. No colour term would be used until an absolute want for it was felt, and then the word employed would probably refer to some substance of a like tint, just as we now use the words carmine, vermilion, indigo, lilac, and violet. We doubt not that a philologist might maintain that those colours which seem to have been the earliest to receive a name, obtained it in this very way, the primitive hunter calling that *green* which was yet *growing*; that *red* which had attained to the quality of *ripeness*, and everything *yel*low which seemed like the egg-*yolk* he loved so well. Their colour names were few, and even now, with all our advance in science and art, one has a difficulty in counting more than some forty distinct names of colours, although, as a matter of fact, the colours themselves are legion. We feel strengthened in this view of the matter, viz., that it was a lack of words, and not of colour discrimination, the ancients were troubled with, when we call to mind that scarcely a century separated Xenophanes from the great painter Zeuxis, whose remarkable imitative power we mentioned at the commencement of this paper.

On these grounds, then, philological evidence does not seem strong enough to warrant the conclusion, that a variegated landscape appeared to pre-historic man of one tint; that, in short, his visual organs were sensible only to quantity, and not to quality, of light. For him there was doubtlessly the same pleasure as for us in viewing the green carpeted earth, the blue vault of heaven, and the glowing tints of sunrise and sunset, and equally well pleased would he be with the colours of flowers and the plumage of birds. Nay, we are inclined to go farther than simply maintaining that he possessed the colour sense, so far, in fact, as to hold that with him the appreciation of colour was so keen, as to lead to its being indissolubly associated with his emotions. With the rosy dawn he was joyful and hopeful; but a landscape suffused with mist, cold and blue, gave him sadness. This tendency has been transmitted to us in intensified form, and we now even avail ourselves of a knowledge of it to increase theatrical effects. To take an example: The opening portions of the French play "Marcel" are particularly gloomy. A father having accidentally shot his son, goes out of his mind. The play represents the endeavours of a loving wife to

restore him to his sanity, by introducing him after a while to his home and surroundings in exactly the same conditions as when the unhappy accident happened, an endeavour in short to induce in him a temporary belief that the last few years have been but a hideous nightmare. In this she succeeds. When the curtain rises on the opening scene, two servants are observed in converse together; they are in the wife's secret, and whilst preparing to receive their insane master dread the issue of events. Sad and gloomy appears everything, and the effect is intensified by suffusing the stage with a *bluish-green* light. The very opposite feeling, pleasing expectancy, is associated in the writer's mind with the very opposite tint, the complementary orange.

One might therefore divide colours into cheerful and sad, and seeing the wonderful dependence of body on mind, the subject becomes one of great importance. Dr. Benjamin Richardson has remarked that although he could not agree with the statement of a learned psychologist, that the effect of colour on the mind is so definite as to determine or modify actual aberration of it, nevertheless he was of opinion that there are healthy and unhealthy colours. Two particularly healthy colours are the two which Nature offers us in her blue sky overhead and green carpet under our feet. The faint grey colour which she gives us in light cloud is a healthy shade for shadow, and the pink and golden tinges which she presents by sunbeam and cloud are, as occasional colours, healthy. Beyond these colours for a room in which many hours of life are passed, all are wrong. He found that dense reds, deep blacks, staring yellows, and blank whites, are painful and fatiguing to the eyes. There is no doubt but that this effect is dependent, to some extent, on one's physical condition; a robust person experiencing little or no inconvenience, where one of finer mould suffers positive pain. It behoves us all, however, to pay more attention to these matters than we have hitherto done, and if we cannot have wall papers suited to every mood of mind, as pictured in Tennyson's "Palace of Art," let us at least have them neither too grave nor too gay, but of the happy mean supplied to us in Nature.

A PIECE OF BLACK-LEAD.

By F. W. Rudler, F.G.S.,

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A PIECE of black-lead appears to have been named on much the same principle as that followed in naming the Speaker of the House of Commons. The Speaker is a man who does *not* speak; the black-lead is a substance which contains *no* lead. It is true that a piece of black-lead presents characters which, at first sight, are strongly suggestive of a metal; but it is easily shown that these characters are only superficial and delusive. If we split open a lead-pencil, and extract the thin rod which forms the axis of the cedar cylinder, we obtain a body which resembles a metal, inasmuch as it possesses a dark iron-grey or lead-colour, coupled with exactly that kind of lustre which we generally regard as characteristic of metallic bodies. The surface of a compact piece of metal always presents a peculiar brilliancy, due to the fact that much of the light which falls upon the surface is thrown back instead of passing into or through the substance; in other words, the light incident upon the surface is neither absorbed nor transmitted to any considerable extent, but is almost wholly reflected and scattered. Now, there are but very few substances, except metals, which possess such a condition of surface as to produce this metallic sheen. Iodine is one of these non-metallic bodies that look like a metal, and black-lead is another.

It is mainly in consequence of the metal-like lustre of black-lead that the material is so largely employed as a polishing agent. When the housemaid rubs the powdered substance upon the cast-iron grate or fender, she produces a reflecting surface which has a metallic appearance; and, at the same time, the thin coating which is thus applied serves to protect the underlying metal from rust. In like manner, though for a different reason, black-lead is extensively used for polishing certain kinds of gunpowder, especially the coarse-grained powder employed for blasting in mining operations. The powder is placed, with the finely-divided black-lead, in revolving barrels, and the corn thus receives a glaze or varnish which protects it from absorption of moisture.

Any conclusion as to the metallic nature of black-lead which may have been suggested by the lustre

and colour of the mineral is likely to be rudely shaken on noting its specific gravity. By merely poising a piece of black-lead in the hand, we may observe how light it is, compared with ordinary metallic bodies. In fact, the specific gravity of black-lead is but little above 2—that is to say, the mineral does not weigh much more than twice its own bulk of water. Advantage is sometimes taken of this comparative lightness in dressing black-lead for the market. It frequently happens that a rock may contain scales of plumbago disseminated throughout its substance, so as to form what has been called "black-lead ore." In such a case it is possible to separate the two substances by crushing or stamping the ore, and allowing the fine fragments mixed with water to flow over a mechanical contrivance, in which the light scales of black-lead and the heavier stony particles roughly sort themselves by virtue of this difference of density. It is scarcely conceivable that these light scales of plumbago can contain a metal proverbially so heavy as lead.

The false notion that black-lead, in consequence of its lustre and colour, must be in some way connected with a metal, is suggested not only by its popular name, but equally by the scientific term *plumbago*, a name derived from the Latin word for lead—*plumbum*. It is worth noting that certain ancient writers made this word do duty for the two distinct metals—lead and tin; in which case the lead was distinguished as *plumbum nigrum*, or black-lead; while the tin was termed *plumbum candidum*, or white lead. How strangely altered is the modern meaning of these terms! Our "white lead" has nothing whatever to do with tin, neither has our "black-lead" any relation to metallic lead.

White-lead and red-lead are bodies which, as everyone knows, are utterly unlike metals; nevertheless they stand true to their names, and really do contain lead, the metal existing in the one substance as a carbonate, in the other as an oxide. But the case is widely different when we come to deal with black-lead, for this mineral, notwithstanding its metallic exterior, is not only destitute of lead, but when in a state of purity contains no metal of any kind. In most cases, however, there is a small quantity of iron accidentally present, and if the plumbago be burnt, this substance is left behind, with other impurities, in the form of a reddish ash.

It is by burning the black-lead that the modern chemist has got at the secret of its chemical composition. If a small fragment of plumbago be strongly heated in excess of oxygen gas it slowly burns away, and were it absolutely pure would ultimately disappear. As a matter of fact, however, there is always more or less residual ash, due to impurities in the black-lead. At the close of the experiment it is found that the oxygen which has taken part in the combustion has been converted into carbonic acid gas. In short, the outcome of the operation is identical with that obtained when a diamond is burnt in oxygen.* A given weight of diamond when completely burnt yields a definite weight of carbonic acid; and if instead of diamond we take the same weight of pure plumbago, we obtain as a product of combustion precisely the same weight of carbonic acid. And just as it is inferred from studying the combustion of diamond that this gem consists of carbon, so the same reasoning leads to the conclusion that plumbago has a similar composition. The black-lead, or plumbago, is in fact a variety of native carbon.

But it is a variety of carbon much less pure than diamond—a fact of which we may be readily satisfied by comparing the quantity of ash usually left when a piece of black-lead has been burnt with that left after the combustion of the same quantity of diamond. It must be admitted, however, that the proportion of ash is extremely variable in different kinds of plumbago, for while some varieties are so impure as to leave a residue equal to one-quarter of their weight, others do not yield more than one-five-hundredth part of their weight of ash. The ash generally consists of silica, alumina, and oxide of iron. It is the oxide of iron which imparts a red colour to the ash, and as this colour is almost invariably present, some of the older chemists were led to believe that the carbon in black-lead must always be combined with iron; whence they described a piece of black-lead, in the chemical phraseology of the day, as a "carburet of iron." Such a view was originally put forth by the celebrated Scheele, and is to be found in old works on mineralogy. It was shown, however, in the early part of this century, by Vanuxem and by Karsten, that the iron in plumbago is not combined with carbon, but exists in the form of an oxide. Moreover, the presence of the oxide of iron is purely accidental, and its quantity is, in some cases, so extremely minute as to be almost inappreciable. We are thus led to conclude that the black-lead, or plumbago, is not necessarily a compound containing iron, but that, when freed from impurity, it is, like diamond, a natural form of the element *carbon*.

* "Diamonds:" "Science for All," Vol. II., p. 194.

Like diamond, again, the plumbago occasionally occurs crystallised. But in this case the forms which the murky mineral assumes are extremely different from those of the brilliant gem. The crystals of diamond are always more or less related to the regular octahedron (Fig. 1, A), but the crystals of plumbago are generally six-sided scales (Fig. 1, B). These two types of crystalline forms are geometrically incompatible with each other,

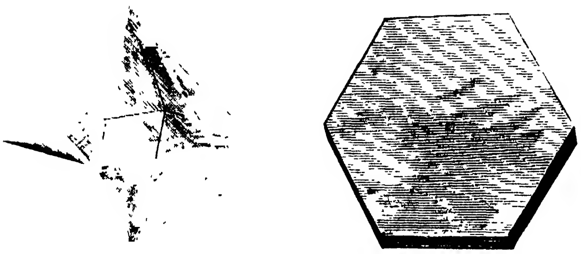

Fig. 1.—Dimorphous Forms of Native Carbon. A, an Octahedral Crystal of Diamond; B, a Six-sided Scale of Graphite.

and represent, in the language of crystallographers, two distinct "systems." When a substance is capable of assuming a duality of form of this kind, it is said to be *dimorphous*, or two-shaped. Carbon offers, therefore, a good illustration of dimorphism; it crystallises in one set of solid shapes in the diamond, and in quite another set of forms in black-lead.

Besides these crystalline varieties, the element carbon is capable of assuming conditions which, being absolutely destitute of crystalline characters, are termed *amorphous*. Charcoal, for example, is an illustration of the perfectly amorphous condition of carbon. So, again, that kind of coal which is called anthracite is practically a natural variety of carbon, yet it never assumes definite geometrical shapes. Such examples serve to show that one and the same elementary form of matter may exist in a variety of states, each offering a new set of physical properties. How different the diamond from the plumbago, or either of these from the anthracite and the charcoal! This power of assuming a diversity of physical properties, while retaining an identity of chemical constitution, has been distinguished as *allotropy*—a term compounded of the two Greek words *allos*, another, and *tropos*, a manner or mode. It is assumed that the change of properties in the several allotropic modifications of carbon must be dependent upon variations in the mode in which the component particles of the body are arranged; that it is, in a word, a *molecular* change. It should be borne in mind that while the ultimate particles of matter are termed *atoms*, the groups formed by the association of two or more atoms are called by modern chemists *molecules*. There are reasons for believing that in each distinct allotrope of carbon, the molecules assume in some way a different mode of arrangement.

Up to this point our studies have led to the conclusion that a piece of black-lead represents an allotropic form of native carbon. Such being its nature, it is obvious that neither the scientific word "plumbago," nor the more familiar "black-lead" is an appropriate name. Mineralogists have therefore cast aside these metal-suggesting words, and usually prefer to distingush the mineral as *graphite*. This word, which was originally introduced by the great German mineralogist, Werner, is derived from the Greek verb, *grapho*, to write; and is quite unobjectionable, since it asserts nothing as to the composition of the substance, but merely denotes its use as a writing material.

This application of graphite as a writing medium depends upon the extreme softness of the mineral. Even the gentle act of rubbing it upon paper, as in using a so-called lead-pencil, causes it to suffer abrasion, so that a portion of the mineral is left behind in a finely-divided state, forming a "streak," which by its dark colour is distinctly visible. In like manner, the softness of graphite causes it to soil the fingers when handled. The same property has led to its use as a lubricating agent for diminishing the friction between the axles of machinery and the bearings in which they revolve.

Mineralogists are in the habit of examining the "streak" of any substance that falls under their notice, inasmuch as it often affords a means of distinguishing one mineral from another. By the character of the streak is really meant the colour of the mineral when in a state of powder, and this is far from being necessarily the same as when seen in mass. The streak may be observed either by scratching the mineral with a substance harder than itself, and observing the nature of the abraded particles, or by rubbing the mineral upon a piece of unglazed porcelain, when a mark is left behind. In the case of so soft a substance as graphite, it is merely necessary to rub it upon paper, when we at once obtain a dark shining streak. There is a rare mineral known as *molybdenite*, which so closely resembles graphite as to be readily mistaken for it; but when rubbed on paper it leaves a streak which, though much like the mark of a lead-pencil, has a slightly greenish tint, and is sufficiently distinct to

serve as a means of discriminating between the two substances.

Lead pencils have become objects of such importance that the finest qualities of graphite, suitable for their manufacture, have considerable commercial value. The only locality in this country which has ever yielded pencil-lead in sufficient quantity to be worked is at Borrowdale, near Keswick, in the Lake District of Cumberland. According to tradition, the deposits were accidentally discovered after a great storm, which overturned an ash tree and laid bare the shining mineral at its roots. Though it is not known when the mineral was first worked, it was undoubtedly a substance of value at least two centuries and a half ago; for James I., in a grant of the manor of Borrowdale, includes "the Wad Holes and Wad, commonly called black cawke." The word *wad* is a local name for black-lead, but it should be explained that by miners elsewhere the term is now used to designate an ore of manganese; it will also be observed that the graphite is called, in the extract from the grant "cawke," a term which is now usually given to the rougher kinds of barytes.

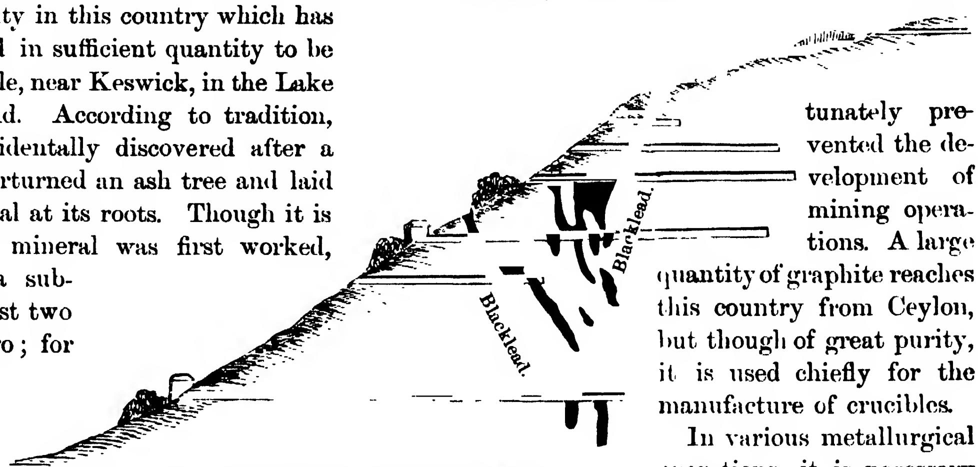

Fig. 2.—Section of the Black-lead Mine at Borrowdale, in Cumberland.

At Borrowdale the graphite occurs in irregular masses called "sops," and in pipes and strings which branch out or die away with tantalising uncertainty. Wad-mining has therefore always been a very hazardous adventure, and men have often been known to work for many years without lighting upon a large and rich nest of the mineral. One of the grandest prizes that ever fell to the lot of the Keswick miner was a large mass of choice graphite discovered in the early part of this century, yielding about seventy thousand pounds of the mineral, and worth upwards of £100,000 sterling. A section of the workings at the Wad-mine is given in Fig. 2.

Coarse graphite, too gritty to be sawn into pieces for the pencil-maker, is often crushed to a fine powder, purified, and re-cemented into a solid block by means of hydraulic pressure. Various foreign bodies—such as sulphur and antimony-ore—may be mixed with the black-lead, since they help to produce a black mark upon paper, but the mark so made is not readily erased with india-rubber.

As it is believed that the deposits of Cumberland graphite are virtually exhausted, recourse has been had to a variety of other localities where the mineral is known to exist, yet it has rarely been found of such high quality as to equal the Keswick wad. Some years ago, some singularly fine specimens were obtained from Siberia by M. Alibert, a Frenchman, but the geographical position of the deposits unfortunately prevented the development of mining operations. A large quantity of graphite reaches this country from Ceylon, but though of great purity, it is used chiefly for the manufacture of crucibles.

In various metallurgical operations, it is necessary to employ highly refractory vessels for the purpose of melting metals. (Fig. 3.) Fire-clay is, of course, the material which forms the staple of these melting-pots, but it is found that they are greatly improved by mixing with the clay a quantity of finely-divided plumbago. At first sight it may seem strange that a combustible substance like graphite can be used with advantage in the composition of vessels which are exposed to very high temperatures. Practically, however, the black-lead in a well-made crucible is so thoroughly kneaded with the clay that each particle appears to be protected, by a coating of clay, from direct contact with the atmosphere; and of course without air, or some other oxygen-supplying medium, it is impossible for even the most combustible body to burn. Curiously enough, the chemist finds that the Ceylon graphite is really much purer than the Cumberland lead, yet it forms so indifferent a material for pencils that it is consigned to the crucible-maker. Hence we may infer that the exceptional value of the Keswick lead for pencil-making depends upon its softness and other physical properties rather

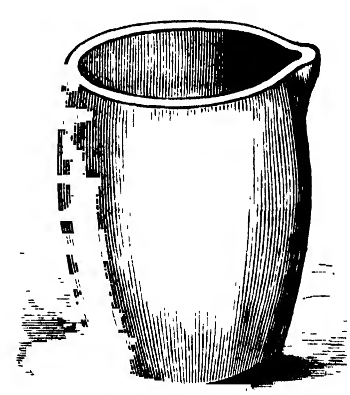

Fig. 3.—Plumbago Crucible.

than upon its being a chemically-pure form of carbon.

It is to be regretted that the conditions under which graphite occurs in Cumberland have not served to throw much light upon the probable mode in which the mineral has been formed. At Borrowdale it occurs in association with certain igneous rocks, known to geologists as diorite and diabase—an association which has led, perhaps rashly, to the inference that a high temperature must needs have prevailed at the moment of its birth. Such a conclusion is supposed to receive some support from the fact that crystalline graphite is occasionally produced artificially in the process of iron-smelting. Cast-iron is capable of dissolving carbon, and if the molten metal has taken up more than it can retain when cold, the excess of carbon separates on the solidification of the iron, in the form of crystalline scales of graphite, which are known to the workmen under the curious name of *kish*. In spite of the suggestive resemblance of kish to natural graphite, it is difficult to believe that the origin of the furnace-product throws much light upon that of the mineral.

Another argument in favour of the production of graphite at an elevated temperature has been drawn from what takes place in the manufacture of ordinary illuminating gas. During the distillation of the coal, it is found that a deposit of dense carbonaceous matter gradually forms as a lining in the interior of the retorts, and from a distant resemblance which this carbon bears to plumbago, it has often been called *gas-graphite*. Such a deposit is formed by the decomposition of some of the hydro-carbonaceous vapours on contact with the hot walls of the retort; whence it has been assumed that if similar vapours were naturally formed within the earth, and were decomposed by coming in contact with the heated sides of a volcanic fissure, they would produce a substance identical with black-lead.

By other chemists, again, it has been suggested, on the ground of experiments made in the laboratory, that certain organic compounds, called cyanides, would certainly yield graphitic carbon if decomposed, under proper conditions, at a high temperature. It may be doubted, however, whether any of these suggestions, ingenious as they are, is likely to scatter much light upon our path in seeking the actual conditions which have obtained in nature during the formation of the mineral. Indeed, the frequent occurrence of graphite in limestones, as in Canada, points in quite an opposite direction. For it appears to be chemically impossible that the free carbon and the carbonate of lime, or limestone, could exist in association at an elevated temperature without decomposition.

A more hopeful quarter from which light may fairly be expected is to be found in those chemical phenomena by which vegetable matter has been converted into carbonaceous substances, such as coal.* Anthracite, as already explained, is a variety of coal consisting almost wholly of carbon, and it seems reasonable to suppose that if the process by which the anthracite has been formed from ordinary coal—whatever that process may have been—could be carried a stage farther, it might yield a yet purer form of carbon, such as we find in graphite. It has occasionally been observed that a dyke of igneous rock cutting through a seam of coal has so altered the material in its neighbourhood as to produce a substance not unlike graphite. Although the exact mode of formation of black-lead is an enigma which has not yet been satisfactorily solved, there is nevertheless a strong belief among chemical geologists that in many cases it must represent one of the final terms in the carbonisation of vegetable matter.

But if we admit an organic origin for graphite, what are we to say when the mineralogist declares that he has found graphite in meteoric bodies? Startling as the assertion is, there can be no question that a form of free carbon, closely resembling a piece of black-lead, is not unfrequently found as a constituent of meteorites.† Admit that our terrestrial graphite is an altered product of vegetable life, and you are almost driven to conclude that the meteoric graphite represents the alteration of celestial organic matter. Can it be possible that in looking at a piece of meteoric graphite you have before you a relic of the vegetable life of another world? The idea is fascinating—so fascinating that it seems a pity it should be cruelly dashed to pieces by the chemist. Yet, to tell the truth, M. Daubrée, a great authority on the chemistry of meteorites, has exactly imitated this meteoric graphite by decomposing the vapour of bisulphide of carbon with metallic iron at a high temperature; and there are strong reasons for believing that we have here a rational explanation of the origin of the meteoric mineral.

Still, it is by no means certain that an experiment made in the laboratory, and yielding a certain result, must needs be identical with the means used in

* "Science for All," Vol. I., p. 84.

† "Science for All," Vol. I., p. 33.

the great laboratory of nature for attaining the same end. Nature is wealthy in resource, and it is likely—nay, certain—that more operations than one have in many cases been brought into play to produce a particular kind of mineral; the same point has been reached by several paths. Possibly, therefore, the graphite from the igneous rocks of Cumberland, and the graphite from the Laurentian limestones of Canada, may have been formed by totally different processes; while the genesis of the meteoric graphite may have been altogether different from either of the others. After all the experiments which have been made in the laboratory, after all the books which have been written on chemical geology, we are bound to confess with frank humility that neither chemist nor physicist, neither geologist nor mineralogist, has yet succeeded perfectly in laying bare the secret workings of nature in giving birth to some of our commonest minerals. As to the origin of a piece of black-lead, it is certain that upon that subject Science has not yet said anything like its last word.

INFUSIBLE ICE: THE BOUNDARIES OF THE LIQUID STATE OF MATTER.

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ALL the various substances of which the earth's crust is composed are capable of existing in three different states—viz., solid, liquid, and gas. Although there are some bodies, such as carbon, which have never yet been liquefied or vaporised, yet there is no doubt that all substances, without exception, will assume these three states when the necessary conditions are fulfilled.

In the present paper we shall treat more especially of the second or liquid state of matter, and in particular, it will be our object to describe the circumstances which condition the formation of a liquid from a solid on the one hand, and from a gas on the other; or, in other words, to indicate those conditions without which the liquid state would be impossible. For the purpose of illustration, we shall confine ourselves almost solely to the consideration of water, as it is the most familiar example.

When water is heated in an open vessel under the ordinary pressure of the atmosphere, *i.e.*, at a pressure equal to 760 mm. (30 inches) of mercury, it boils at a temperature of 100° C. (212° Fahr.). If, however, the pressure is other than that just named, the water no longer boils at 100° C.; for we find that the boiling-point falls lower and lower as we diminish the pressure, whilst if we increase the pressure the boiling-point rises. An increased pressure, therefore, prevents the water from boiling so easily—*i.e.*, it renders the conversion of the liquid water into gaseous steam more difficult; whereas a diminution in pressure facilitates this conversion.

Aqueous vapour exerts an expansive force or tension, the amount of which increases with the temperature, but this is continually counteracted by the pressure of the overlying atmosphere. There is in fact a continual struggle going on at the surface of any liquid freely exposed to the air, the opposing forces being the tension of the vapour of the liquid and the superincumbent pressure of the atmosphere. Now, as the pressure of the atmosphere is not influenced by the temperature of the liquid, whilst the expansive force of the vapour from the latter rapidly increases as the temperature rises, it follows that the two opposing forces continually become more and more nearly balanced as the liquid becomes hotter and hotter, until they are exactly equal and the tension of the vapour is just on the point of getting the upper hand. When this is the case the liquid begins to boil. The boiling-point of a liquid, therefore, marks the temperature at which the tension, or expansive force of its vapour, is equal to the superincumbent pressure of the atmosphere in which the liquid is placed. We may, therefore, define the boiling-point of a liquid as that temperature at which the tension of its vapour is equal to the superincumbent pressure. This being the case it is readily seen why the boiling-point should rise or fall, according as the pressure is increased or diminished. For this reason water boils more readily as we ascend a mountain; so that at the top of Mont Blanc, for example, it boils at a temperature so low that it does not get hot enough to cook potatoes.

For a given pressure there always corresponds a definite and fixed boiling-point. The following

table represents the boiling-points of water corresponding to a number of different pressures:—

Boiling-point.	Pressure.	Boiling-point.	Pressure.
—30° C.	·39 mm.	80° C.	354·6 mm.
—20	·93	100	760·
—10	2·1	120	1,491·
0	4·6	140	2,718·
+10	9·2	160	4,652·
20	17·4	180	7,546·
30	31·5	200	11,689·
40	54·9	220	17,390·
50	92·0	240	24,900·
60	148·8	260	32,700·

If now, from such a table, we construct a curve showing the relation between boiling-point and pressure, we find that this curve has the form represented in Fig. 1. The curve is constructed

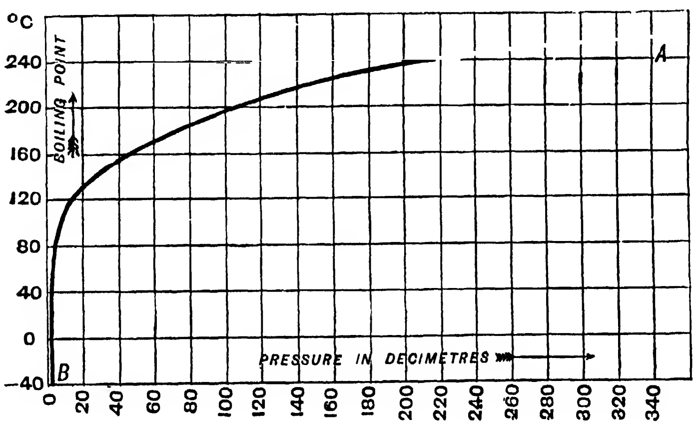

Fig. 1.—Diagram illustrating the Relation between Boiling-point and Pressure.

by taking two lines at right angles, one horizontal and the other vertical, and marking off on the horizontal line the pressures, and on the vertical line the corresponding boiling-points, and then producing from each of the corresponding points lines till the latter meet. In this way a number of points are obtained at which the intersections occur, and by joining all these points by a line we get the curve in Fig. 1, showing the relation between boiling-point and pressure.

This curve shows that at its upper end (A) a very large increase in pressure makes only a slight increase in boiling-point, while at its lower end (B) the reverse is the case, for there even a minute alteration in the pressure makes a considerable alteration in the boiling-point. In other words, the curve at its upper end becomes practically horizontal, and at its lower end almost vertical. Now, what do these facts mean? The fact that the curve at its upper end (A) becomes horizontal shows that if the water be above a certain temperature (370° C. or 698°F.), called its critical temperature, no increase of pressure, however great, is capable of making any alteration in the boiling-point, or if we have steam above this temperature we cannot condense it to a liquid by pressure, no matter how great, whereas we can do so even if the temperature be but 1° below this point. This same conclusion was arrived at some years ago in another way by Dr. Andrews of Belfast, and, more recently, by Mr. Hannay of Glasgow.

The point, however, to which attention is more especially directed is the lower end of the curve (B). Now, it has been found in the case of all substances which have been subjected to experiment that if we reduce the pressure sufficiently the boiling-point always falls below the melting-point; in other words, the substance under these circumstances boils before it melts—*i.e.*, while it is still solid—passing over into the state of vapour without undergoing any previous fusion. If this be true, it would follow that if we *maintain* the pressure below that which corresponds to the boiling-point at the temperature at which the substance melts, it would not be possible to melt the substance, however strongly it might be heated; in fact, we might have ice in a red-hot vessel and yet it would not melt, but rapidly sublime away into vapour without passing through the intermediate state of liquid.

From what has been said, it will be seen that there are two conditions which must be fulfilled in order that any substance may exist in the liquid condition, viz.—

(1) The *temperature* must be *below* a certain point, called the *critical temperature* of the substance, otherwise the substance can only exist in the state of a gas, which no amount of pressure, however great, can liquefy.

The reason why so many chemists failed to liquefy hydrogen, oxygen, air, and the other so-called permanent gases, though they employed enormous pressures, was because they did not cool the gases below their critical temperatures. Pictet and Cailletet, however, obtained this necessary condition, and so succeeded, towards the end of 1877, in making, independently of one another, their brilliant discovery of the liquefaction of these gases.

(2) The *pressure* must be *above* a certain point called the *critical pressure* of the substance, otherwise the solid substance cannot be liquefied, however

great the heat applied, but is converted directly into the state of gas.

Now let us apply this last statement in the case of ice. If that statement be true, we ought to find it impossible to melt ice even with the strongest heat, if at the same time we take care to keep the pressure on the ice below its critical pressure. In order to submit ice to this test the great difficulty is to *maintain* a sufficiently low pressure, since the critical pressure for ice is exceedingly small—viz., equal to 4·6 mm. (about one-fifth of an inch) of mercury. It would be easy enough to obtain so low a pressure as this, but the difficulty is to *keep* it below this point in a vessel in which large volumes of steam are being evolved ; for it will be easily understood that if the ice be but slightly heated, the quantity of vapour given off would soon be sufficient to raise the pressure beyond the critical pressure. This, however, can be done by an arrangement involving the principle of Wollaston's cryophorus. For this purpose, the vessel in which the ice is placed is connected with a large chamber, called a condenser, which is kept at a very low temperature (about – 18°C. or 0°F.) by surrounding it with a freezing mixture of salt and ice. In this condenser, the steam given off from the ice is condensed by the great cold as fast as it is formed, so that it is prevented from exerting pressure, and thus the pressure on the ice is maintained below the critical pressure. The details of the arrangement are shown in Fig. 2.

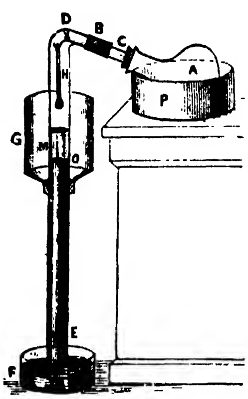

Fig. 2.—Experiment illustrating the "Critical Pressure."

A strong glass flask (A), holding about a quart, acts as the condenser. It is provided with a very tight-fitting cork, and glass tube (C) passing through the cork, which is well fastened down by copper wire and wax. C is connected with the end of the glass tube (D E) by a piece of stout india-rubber tubing, a thermometer (H) having been previously attached, by the wire (X), to the lip of the tube at B. The tube (D E) is about 1 in. diameter and about 4 ft. long. The bottle (A) and tube (D E) are completely filled with mercury, the thumb placed over the end of the tube at E, and the whole inverted over the trough of mercury (F), as shown in the figure, so that the mouth of the tube dips below the surface of the mercury in F ; then on removing the thumb the mercury falls to the point O—*i.e.*, the ordinary height of the barometer. The mercury is then run out of A by tilting up the bottle and inclining the tube (D E). By this means a large Torricellian vacuum is obtained in A, and the upper part (D O) of the tube. The whole apparatus is in fact nothing more than a barometer with a large bulb at its upper end, which is bent down through rather more than a right angle. D E is next brought to the vertical, and the bottle (A) placed in the trough (P). An inverted tin bottle (G) without a bottom, is fitted with a cork, so that it may slide somewhat stiffly along D E.

To begin with, the tin bottle (G) is placed in the position shown in the figure, and filled with a freezing mixture of salt and ice. Some water, previously boiled to expel dissolved air, is then passed up the tube (D E), sufficient to form a column at M, about 2 in. deep, the thermometer (H) having been previously arranged so that its bulb might be about 2 in. above the surface of the water at M. The trough (P) is next filled with a freezing mixture of salt and ice, in order that any vapour given off from the water at M may be condensed in A as fast as it is formed, and thus the internal pressure can never exceed about 1·0 to 1·5 mm. ($\frac{1}{20}$ in.). When A has been sufficiently cooled, which requires about fifteen minutes, the tin vessel (G) is slid down the tube (D E), and its freezing mixture removed. The water at M will then have solidified to a mass of ice, which, on heating with the flame of a Bunsen's burner, melts either wholly or partially, and the liquid formed begins at once to boil, owing to the low pressure; so that here we have the water boiling even while a portion of it is still unmelted. The fusion commences at the bottom of the column of ice, whereas the upper part only melts with difficulty, and requires a very strong heat. The fusion of the ice in this case is due to the steam evolved from the lower portions of the ice-column being imprisoned and unable to escape, and hence producing pressure sufficient to cause fusion. When the greater part of the ice at M has been melted, the lamp is removed, and the tube surrounding the water is tightly clasped by the hand, the heat of which, under the low pressure, is sufficient to produce a somewhat violent ebullition. The liquid, in boiling, splashes up the side of the tube and on to the bulb of the thermometer, where it freezes to a solid mass, as represented in Fig. 3. If now the tube at the points indicated by the arrows be strongly heated by the flame of a Bunsen's burner, the following phenomena will be observed :—The

ice attached to the sides of the tube at first slightly fuses, because the steam evolved from the surface of the ice next the glass, being imprisoned between the latter and the overlying strata of ice, cannot escape, and hence produces pressure sufficient to cause fusion; but as soon as a free passage has been made for the escape of the steam, fusion ceases, and the whole remains in the solid state, and neither the ice on the sides of the tube nor that on the bulb of the thermometer can be melted, however strongly it may be heated. The ice merely volatilises without previous melting, because the steam being condensed in A as fast as it is formed, the pressure never rises above the critical pressure.

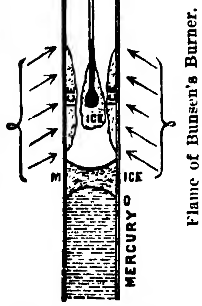

Fig. 3.—Ice remaining under the Application of Heat.

The chief conditions for the success of the experiment are:—1. That the condenser (A) is sufficiently large to *maintain* a good vacuum; 2. That the ice is not in too great mass, but arranged in thin layers; 3. The passage to the condenser must be kept open, so that the steam coming from *all parts* of the ice may have a free vent.

The above experiment shows, then, that in order that ice may melt, it is necessary that the pressure should be more than a certain amount—*i.e.*, above its critical pressure. All that the heating does is to make the ice pass away into steam without first forming liquid water, as is the case under ordinary circumstances.

The same remarks apply to other substances besides ice, so that we cannot melt them if we keep the pressure below their respective critical pressures. This critical pressure is different for different substances. To prevent some bodies—such as camphor, mercuric chloride, iodine, &c.—from melting it is only necessary to reduce the atmospheric pressure by a small amount, because the critical pressures of these substances are not very much less than the ordinary pressure of the atmosphere. This may be very easily shown in the case of ordinary camphor as follows:—A glass tube about two feet long and one inch diameter is closed at one end, and about one quarter of it filled with camphor. The other end of the tube is then connected with an air-pump, and the camphor heated with a lamp, when it melts and begins to boil. If, now, when the whole of the camphor is melted and ebullition has fairly set in, the pump be worked, the pressure is reduced below the critical pressure of the camphor, and the latter instantly becomes solid, and this frequently with the first stroke of the pump, notwithstanding the camphor is being strongly heated during the whole of the operation. If the pump be continued working, it is quite impossible to melt the camphor, no matter how great the heat applied. In making this experiment care must be taken to prevent the air-way being choked up by the condensation of the camphor-vapour.

Many substances—such as metallic arsenic, white arsenic, ferric chloride, &c.—cannot be melted under ordinary circumstances, because the ordinary atmospheric pressure is less than their critical pressures; but if the pressure be increased by artificial means, these otherwise infusible substances can be readily melted.

Let us now return to the ice experiment. We have seen that if we keep the pressure below the critical pressure for ice it is impossible to melt the ice. But this theory of critical pressure, though it tells us that the ice cannot be melted on heating, gives us no information as to whether the ice under these circumstances remains at the freezing-point (all the heat applied being used to convert it into steam without raising its temperature), or whether it actually rises in temperature and becomes hot. This point being of very great interest, many experiments were made with the greatest care in order to determine it. The results of these at first appeared to show that the ice did become hot; and such a conclusion, upset as it was afterwards by more precise observations, offers an instructive example of the precaution necessary in arranging critical experiments to determine matters of this kind, and in drawing conclusions from them. The thermometer, H (Figs. 2 and 3), was so arranged that its bulb was covered with ice, and in a number of different experiments, when the ice was strongly heated, the thermometer rose to temperatures in some cases as high as 180°C. (356°F.), or very much hotter than boiling water, and yet the ice did not melt, but had either been wholly converted into vapour, or had become detached from the bulb of the thermometer. To obtain these results it is necessary that a very strong heat be applied, otherwise it is all used up in converting the ice into steam without raising its temperature; the heat must, in fact, it was said, be applied more quickly than it can be absorbed for changing the solid ice into gaseous steam. And this was supposed to be the reason why some experimenters were not able to get the thermometer to rise in

temperature when imbedded in the ice. Of course it was at once perceived that though the thermometer in the above experiments rises far above the ordinary melting-point for ice, yet it did not necessarily follow that the ice was really hot; for it might not actually touch the thermometer, except at a few isolated points, being separated from the ice by a thin film of vapour. The supposed hot ice was therefore dropped, at Prof. Roscoe's suggestion, into a known weight of water at a known temperature, and in various experiments which were made in this way the water was distinctly warmed, appearing to show that the ice in both cases must have been above 80° C. (176° F.), for had it been less than this it ought to have cooled the water; because ice in melting requires for its fusion as much heat as would be necessary to raise its own weight of water from 0 to 80° C. (32° to 176° F.). From the extent to which the water was heated in one of the experiments, the temperature of the ice was even calculated to be 122° C. (252° F.), or 22° C. (40° F.) hotter than boiling water.

Nevertheless the conclusion apparently thus reached was ultimately reversed. Further and more precise observations showed that the temperature never rose above 0° C. so long as the bulb of the thermometer remained *completely* covered with ice; but that as soon as even a very small portion of the bulb became bare, the temperature began to rise, and steadily increased as the bulb became more and more exposed. Thus it was proved that the apparent rise in temperature in the earlier experiments, was due to direct radiation of heat from the hot tube to the bulb of the thermometer, but that the ice, though infusible, did not itself really rise in temperature above zero.

The main conclusion, however, has been absolutely established, that under the critical pressure the ice will not melt, however strongly heated, but passes directly into vapour. From such experiments the further general conclusion follows, that in an absolutely perfect vacuum the liquid state of matter would be impossible; a conclusion which leads further to some very interesting reflections concerning the constitution of the universe.

A BROWN SEA-WEED.

By E. Percival Wright, M.A., M.D., F.L.S.,

Professor of Botany in the University of Dublin.

THE name "wrec," or sea-ware, has been from remote times applied to the marine sea-weeds when thrown on shore Early charters made wrec the property of individual proprietors. Dr. Johnston tells us of one of 1228, which confirmed to the prior and convent of Durham certain rights. Among these was the right to gather, use, or sell "the wrec." In the opinion of some farmers a cart-load of good ware or wrec is at any season of the year equal to a load of farm-yard manure, but at the barley-sowing time it is worth double; and ware-barley was at one time much esteemed by brewers. Some of the brown sea-weeds at last came to be distinguished as tangle and wrack. Of the latter, the following is a short account One of the commonest species of sea-wrack is known as *Fucus vesiculosus*, the "brown bladder-wrack." The generic name, *Fucus*, was given it by the great botanist, Linnaeus; it is Latinised from the Greek, *phacos*, which means a sea-weed, and certainly, so far as the whole north of Europe is concerned, there is no sea-weed more generally known. The second, or specific name (*vesiculosus*), was also given to it by Linnaeus, and has reference to the oval-shaped, bladder-like cavities or vesicles which are found here and there throughout the surface of the plants, filled with air—how often, as children, have we burst them! Commonly and widely diffused as this sea-weed is, it is within quite recent times only that we have learnt its whole life history. The story of this life will serve in great measure for that of an entire section of the so-called olive-coloured algae, and therefore we must treat of it a little in detail.

To clear the way before us somewhat, let it be understood that the whole structure of this, as of any other sea-weed, is built up of simple cells. Now a cell is a mass of a semi-viscid or sometimes granular substance called *protoplasm*,* which is mostly surrounded by a membrane called the *cell-wall*. Countless numbers of these cells, more or less intimately united together, and *all* more or less assuming the same general form, constitute the

* "Science for All." Vol. I., pp. 295, 296, 297, 378.

leaf-like expansion known as the *thallome*, so that in proceeding to describe a fully-grown plant of the sea-wrack we will be describing the various peculiarities assumed by its thallome. In most works on British sea-weeds this thallome is known under the name of *frond*, and by this name we shall, on account of its familiarity, continue to designate it.

Let us now imagine that we have a frond of *Fucus vesiculosus* before us (Fig. 1). If living near a rocky part of our sea-coast, nothing is easier than to obtain specimens, and even if inland, this sea-

Fig. 1.—Portion of *Fucus vesiculosus*.

weed is so commonly used to pack lobsters, crabs, and oysters with, that no doubt morsels of it can easily be procured. If the specimen has been taken carefully off the rock on which it grew—not simply cut off—the part by which it was attached to the rock will be found to be somewhat disc-shaped. The cells have here grown out into a flattened or slightly-elevated mass, closely adherent, which serves the purpose of rooting the whole frond firmly to the rock on which it from the first grew, though in reality the root-like part only serves as an anchor, and does not, as in flowering plants, play an important part in the nutrition of the sea-weed. From this root-like portion the frond arises. The appearance and shape of this will vary immensely both in size and outline. Specimens may be met with near high-water mark, and in muddy ground, not more than an inch in length, while others growing near low-water mark, and on the sheltered side of some pier, may be found with fronds of upwards of three feet in length. The fronds will also vary quite as much in width, being sometimes not wider than the eighth of an inch, and sometimes a full inch in width. They are flat, and have a leather-like feel. They soon become branched, these branches being at first two in number, and each of these branching into two again. But while this branching forms thus a series of twos, the branches are not always equal in size. The edges of the frond and its branches are even, like the edges of a hyacinth leaf, and along the central portion of both there runs a thicker cord-like portion called the mid-rib. Here and there, but chiefly in the upper portions of the branches, inflated bodies will be seen, mostly in pairs, and to the left and right of the mid-rib. If these in a fresh condition are pressed between the finger and thumb, they will be found to be highly elastic, and if much pressure is used they will burst. These are the air-bladders, which, from their very constant presence, give the name to the species. In size, they vary in proportion to the diameter of the frond. The substance of the frond is tough, and, while it will tear into strips, it cannot easily be broken across. Its colour is of a dark olive brown, which is of a lighter hue in young specimens.

So far the appearance of this frond can be seen by the unassisted vision, but if we wish for a more intimate knowledge of its structure we must make

Fig. 2.—Cross Section of Frond of *Fucus vesiculosus*

a section through—let us say—the whole frond, right across the centre of one of the air-bladders. If we now take a very thin slice (Fig. 2) from this section, one so thin that the light will have no difficulty in penetrating it, and examine the same with a low power of the microscope, it will be found that the whole is formed of a system of cells, and that although these are all referable to one type, yet that here and there they present somewhat different forms,

and that their walls are of somewhat different consistencies. The outer portion will contain a series of cells one or two layers deep, with thickened walls, and the outer walls of the outer layer will show a thin skin-like pellicle. This series we may call the rind layer. It is this we come in contact with if we pull the frond through our fingers, and it is this which gives to the touch the slimy feel when the frond is quite fresh. Within this layer, other cells of the same nature, but with less dense cell-walls, are to be seen. Then we come to the large empty spaces, caused by the rapid growth of the surrounding cells, and which form the vesicles or air-bladders, and between these the mid-rib is found to contain cells of a peculiar shape—longer than broad—running in many rows, mostly parallel to one another, but sometimes interlacing with one another, and thus giving to the frond its well-known rigidity. These last-mentioned cells are better seen, and their shape is easier to be understood, if the section be made not transverse to the axis of the frond, but vertically; then they will be seen to run like threads through the centre of the frond, and to be surrounded by the two outer layers of cells above alluded to. The reddish-brown colouring matter (phycophæine) conceals, as it were, the leaf-green colouring matter (chlorophyll), which, however, is always present, and in very young specimens may even be seen.

So far we have been considering the barren frond; but this sea-wrack developes organs, the functions of which can be compared to those of the stamens and pistils on a flowering plant.* These algæ fronds, when fertile, are either male or female; and their organs of fructification present much of interest. They are to be found crowded around the summit of some of the branches (Fig. 1), and consist of little spherical cavities plunged, as it were, in the rind layer of these portions of the frond; these cavities are known as "conceptacles," and in our plant these conceptacles are on the same frond either all male or all female; in both cases the cavities will open out by means of a pore, from which will ultimately escape the reproductive bodies. From July to the end of May, all along our southern shores, these conceptacles will be found more or less developed on most of the adult fronds. If we cut through a male conceptacle, and examine it in the same way that we did the slice through the frond (Fig. 2), we find the hollow portion filled with a forest of delicate filaments, growing outwards from the cells forming the floor and side walls of the cavity; these filaments are composed of cells, which elongate by a form of cell growth called "apical cell growth," and which also give rise to numerous side cells, which often grow into branch filaments after a like fashion. The cells composing these filaments, thus enclosed within the male conceptacle, are of two sorts. In the first the protoplasm either adds to the filament, or, as in the second, the protoplasm divides itself into an immense number of particles,

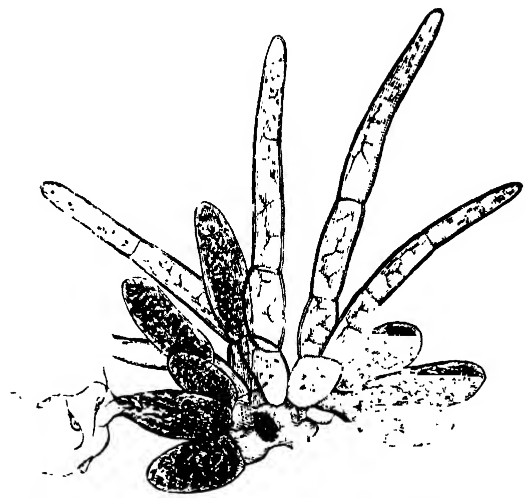

Fig. 3.—Male Organs of *Fucus vesiculosus*: Antheridia with Antherozoids escaping.

which are each furnished with two curious whip-like bodies (cilia), and which particles burst out through the cell wall, and by means of their cilia vibrate most rapidly about. Multitudes of them escape together, and most of them make their way to the common pore or opening above referred to—these are the male organisms (Fig. 3); these functionally are like the pollen bodies in the flowering plants; these can no more grow up into little plants of sea-wrack than the pollen bodies of a cactus flower could give of itself origin to cactus plants. What is their fate? We shall see in a moment; but we must first describe the female conceptacle (Fig. 4).

In their general shape and appearance these are very like the male conceptacles, but on an examination of their contents, we find the forest-like mass of filaments somewhat less branched—more like rigid jointed hairs—and the cells with the dividing protoplasm are now of proportionally much larger size; besides, these cells never give origin to more than eight daughter cells, whereas the corresponding ones in the male conceptacles give origin to quite a swarm, and the daughter cells also are not furnished with locomotive cilia.

* "Science for All," Vol. II., p. 215; Vol III., p. 26.

When these female organisms are expelled out of the pore in the female conceptacle, partly guided thereto by the long hair-like filaments, they fall into the salt water, and if the reader has followed the description so far, he will remember that at this moment, they are nothing but little globe-like bodies of soft protoplasm, which by themselves would soon die; but if in their first entrance into an independent life, they meet with any, even one, of the bee-like swarm of male organisms which are rapidly flying about by means of their whip-lash-like bodies, these at once impinge upon them, and the two functionally distinct masses of protoplasm mingle their substances; the larger mass is fertilised by the smaller, and the product of the fertilisation subsiding on, or being borne to the

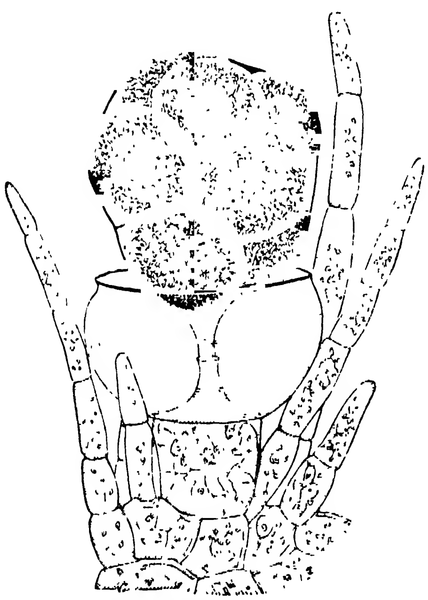

Fig. 4.—Female Organs of *Fucus vesiculosus.*

nearest rock, will soon be surrounded by a cell wall. Next this cell will divide into two portions: one, the lower, will attach itself to the rock, giving rise in time to the disc-like root already described; the other, the upper, will grow up in time into the mid-rib part of the future frond, giving off the flat wing-like portions as it grows. Thus, we here come back to the stage of our plant-life from which we started, and we can understand that however complicated its structure was, as we tried to examine it in its full-grown form, we traced that life back until we found it start out of two differently-sized and functionally distinct masses of protoplasm; and these too alike in this, that they at one time formed part of the very protoplasm of the plant itself, but were eventually set free, so as to carry on the life not of the individual plant, but of the species of plant to which that individual belonged This form of reproduction of the species may be called true reproduction (sexual), and the product thereof may be called a true individual. In that large group of the brown sea-weeds to which our plant belongs no other form is known, and in this group we have several well-known genera and species, all of which will be found fully described in any work on British sea-weeds.

Belonging to the same genus as the species above described, is the serrated sea-wrack (*Fucus serratus*), also very common, and easily distinguished from the former by the absence of air-cavities and by the deep toothing or serrations (*serratus*) of the edges of the fronds; and the conceptacles arise more on the flat surface of the tips of the fronds than in terminal tufts, as in the bladder-wrack. This species, too, is confined to the Atlantic coasts of Europe, and does not, like *F. vesiculosus*, extend to the Pacific nor into the Mediterranean Sea. The other two British species of this genus are more rarely to be met with. In *Fucus ceranoides* there is a resemblance to *F. vesiculosus*, but the absence of the air-bladders will at once distinguish between these two, while the edge of the frond being smooth will distinguish between it and *F. serratus*. It frequents land-locked bays and estuaries, and seems to like a little admixture of river water with that of the sea. The tufts of conceptacles arise in corymb-like masses from the lateral branches of the fronds, which are about half the width of the barren branches. The male and female cells are to be found on different plants in these species. In *Fucus Mackaii* the fronds are quite peculiar, being cylindrical, and not, like all the other species, flat, and these grow in globular masses or tufts about the size of a human head, which seem not to be attached to rocks or stones, but to anchor themselves among the mud or loose stones. The mass of conceptacle-bearing cavities form grape-like bunches which hang from the ends of some of the lateral branches. This species, which is found on the west coasts of Ireland and in Scotland, would well repay a thorough examination. Another pretty common species is known as the knotted sea-wrack (*Ascophyllum nodosum*). This is put into a genus separate from the others for a reason, among others, perhaps easily understood. There are, as a rule, never more than eight daughter cells formed in each spore-producing cell of the female conceptacles of the species already enumerated, but in

those of this giant fucoid only four are to be found. The root-like portions of this species are often two inches in diameter; the fronds will sometimes grow to a length of five or six feet; the air-bladders will be one to two inches long; the edge of the frond is toothed, but the serrations are far between. From the axils of some of these spring the pear-shaped masses of conceptacle cavities—bright yellow when the spore masses are ripe. This species is common on the Atlantic shores of Europe and America, and used to be largely burnt for the manufacture of kelp. Another interesting species is called *Pelvetia* (or *Fucus*) *canaliculata*, which often is to be seen growing so far removed from low-water mark as to be only within reach of the spray. Under such circumstances the little tufts look very unlike a fucoid. It never seems to care to venture itself lower down than to be within the reach of half tide. Thus it happens that on hot summer days the fronds may be found apparently quite dried up and withered, and yet these on the return of the tide, or even by the splashing up of the salt spray, will soon lift up their heads and recover all their former freshness. Both sexes are to be found in the same conceptacles. In *Bifurcaria tuberculatus* the root-like portion is composed of branching fibres. The frond is thick, composed of round goose-quill-like branches. Like the last-mentioned species it is hermaphrodite.

In the genus *Cystoseira*, of which there are five British species, the fronds assume a bush-like form. There is a thickish stem—perennial—with more or less numerous branches; the air-bladders are often arranged in rows, whence the name (*kustis*, a bladder, and *seira*, a chain). The largest and finest species is *C. fibrosa*, one of the most beautiful is *C. ericoides*; both are pretty common, so also is *C. granulata*. *C. discors* is not so common, and the fifth species, *C. barbata*, is probably not a native. In the Sea-thong (*Himanthalia lorea*), the portions of the frond which bear the conceptacle cavities are of annual growth, and the perennial vegetative portions are reduced to little cup-like bodies well known to collectors. The male and female conceptacles are on different fronds, and the female mother-cells only give origin to one daughter-cell, not to four, as represented in Professor Harvey's pretty plate.* In all these forms of fucoids it will be noticed that the air-bladders when present are found immersed in the frond. But we must very briefly call attention to two genera included in the native flora, in which these are stalked, thus standing out like little floats. The first of these, scarcely admitted by some into our flora, is the genus Sargassum, to which the Gulf-weed (*S. bacciferum*) belongs. Its generic name is said to be derived from the Spanish sargazo, the name given to it by the early navigators. Its air-bladders being like berries justify its specific name. A true native and the last species to be noticed is the Sea-oak (*Halidrys siliquosa*), a very handsome and not uncommon form. The air-bladders are not only stalked, but arranged in transverse partitions looking like pods, or the inflated lomenta of the radish.

We have thus enumerated all the native species. This group of the sea-wracks, however, by no means contains all the algæ with a brown colouring matter in their cells. On the contrary, the group stands out as one quite singular in this, that it has but the one form of reproduction above described. Another form must be very shortly noticed. It is where the contents of a cell or cells break up into a large number of cilia-bearing masses of protoplasm, not unlike the male particles (antherozoids) already described, but differing from them enormously in function, inasmuch as each one of them can grow up into a perfect frond. These tiny spores, thus endowed not only with life, but with a power of living and developing unaided, are well called zoo-spores. There are no zoo-spores in the fucoids, but they are to be found in the great sea-tangles (*Laminaria*), and in the wonderfully common *Ectocarpi* known to every sea-weed collector as a genus of filmy silky brown-sea-weeds, to be found in every rock-pool, and often growing in tangled masses from the fronds of the sea-wracks. In another section of brown weeds, which includes the very lovely peacock-tail algæ (*Padina pavonia*), only to be found very rarely on British shores, and the common *Dictyota dichotoma*, these zoo-spores have lost their power of locomotion, and being developed in the mother cells always four in number are called tetra-spores (four spores). We have already seen a good deal of this last type in the account of a red sea-weed.† There are thus three sections of the brown sea-weeds:—1, without zoo-spores (Azoosporeæ)—the life history of this section we have studied as above; 2, with zoo-spores (Zoosporeæ); and 3, with tetraspores (Tetrasporeæ). The life history of these last is full of interest, and may be given hereafter.

* "Phycologia Britannica," Vol. I., Plate iv.

† "A Red Sea-weed:" "Science for All," Vol. III., p. 319.

The fucoids are widely distributed throughout the cool waters of all the oceans, diminishing sensibly in the warm semi-tropical or tropical parts. Around our own shores, wherever these are rocky, they like being alternately exposed to the atmosphere, and, covered by the sea, they thus form a most characteristic feature when the tide is out. From the toughness of their fronds, very few of the group of the fucoids will adhere to paper when drying, and from this peculiarity and their comparatively large size they are not favourites with sea-weed collectors, by whom they are accordingly not gathered nor stored up like their beautiful green and red allies. They have nevertheless a deeply interesting history of their own, and from an economic point of view they are worth all the others put together, for they supply manure to the farmer, and though more economic sources of supply have gone far to oust them from their former monopoly of yielding iodine, yet in Orkney, Shetland, the Western Islands of Scotland, and other primitive parts of the coast "the dull weeds" still maintain an honoured place in the farmers' and fishermen's domestic pharmacopeia.

SUNSET, TWILIGHT, AND HALOS.

By the late Robert James Mann, M.D., F.R.C.S., F.R.A.S., F.M.S., etc.

THE globe-shaped earth is enveloped in an investment of air, which extends for a long distance away from the solid surface upon which man dwells, out towards the far-stretching void of space,* so far, indeed, that it catches the rays of the sun upon its topmost heights, and there shines with the illuminating glare, when the radiant source of the light is itself plunged beneath the horizon of the place where the observer stands.

Those shining aërial heights are then, in this particular, like the summit of a mountain tipped with sunshine, whilst the valley at its base is still dark with the shadow of night. The air-summit, indeed, is so much higher in its stretch than the loftiest of the mountains that, as a matter of fact, it is basking in the light when their tops are still covered with gloom. The twilight, which is so familiar to everyone, is thus properly the top of the air, tinged with the rays of the horizon-hidden sun. Small as the air-particles are in their isolated individualities, they nevertheless cluster round the earth, in such overwhelming abundance, and crowd behind each other in such densely serried ranks, that they shine through their depth under the far searching rays as an impenetrable, solid surface might do. The twilight may thus, in strict accuracy, be defined as the summit of the air illuminated by the direct beams of the rising or setting sun, and seen from the regions below, which are still covered by the sable shadow of the protuberant earth.

The heights of mountains can be calculated by skilful mathematicians, from the length of time which elapses after the first touching of their highest peaks by the beams of the sun, before the face of the luminary itself rises into light on the low ground around their base. The higher the peak, the longer the interval which thus intervenes. This is most easily understood from a consideration of the way in which the heights of the mountains in

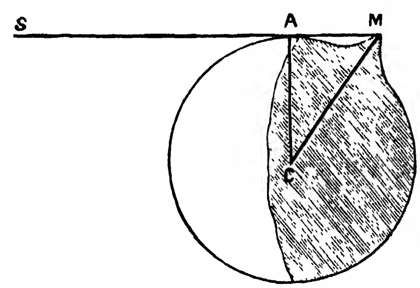

Fig. 1.—Showing how the Heights of the Mountains in the Moon are measured.

the moon have been measured by astronomers. All the chief mountains in the moon, which can be seen from the earth by the help of a telescope, have had their heights ascertained in this way. The German observers Beer and Maedler have calculated the heights of not less than one thousand and ninety-five lunar mountains. As the front edge of the sunshine sweeps on over the spherical surface of the moon, sparkling islands of light start up in the darkness, in advance of the boundary of the spreading illumination. These are all mountain-tops which have caught the sunbeams before they have reached the lower valleys round. The appearance of these isolated specks of brilliant light, dotted out in front of the general field of sunshine advancing

* "Science for All," Vol. I., p. 327.

upon the face of the moon, is one of the most interesting of the spectacles which have been provided for human sight by the power of the telescope. The process by which the heights of the mountains are found, by measuring the distances of these shining spots from the boundary of the general illumination of the moon, is a simple application of one of the fundamental principles of trigonometry, which may be in some measure understood by a consideration of the accompanying diagram (Fig. 1).

If, in this diagram, the circle be taken to represent the visible hemisphere of the moon, half in sunshine and half in shade, and about the period of the fourth quarter of the lunation, S A being the line along which the rays of light pass from the sun, A being the boundary of the illuminated portion, M being the top of a lofty mountain, which rises out of the shaded part, and just catches the sunshine as an isolated spot, and C being the position of the centre of the moon; then a triangle is formed between C, M, and A, in which the line C A is the distance of the surface of the moon from its centre, or, approximately, 1,000 miles. A M is the distance of the mountain top from the border-line of sunshine, a quantity which can be found in proportional parts of the diameter of the moon by direct observation; and the line C M is the distance of the mountain top from the centre of the moon; or, in other words, a radius of the moon (1,000 miles) with the height of the mountain added to it. In this triangle, the lengths of C A and A M being known, and the angle C A M being necessarily a right angle, because the line A M is a tangent to the circumference of the sphere, the length of the side C M, which consists of the height of the mountain and the radius of the moon, can be easily calculated by the processes of trigonometry that deal with the well-known properties of triangles. The length, which is deduced as the measure of the side C M, is, in this case, exactly the height of the mountain added to the 1,000 miles. By a similar process the attempt has been made to ascertain the height of the outermost layers of the air. It is observed how far the sun has to sink beneath the horizon before the topmost summit of the air is cut off from its rays. A competent authority, M. Bravais, some years ago made a series of observations of this character from the top of the Faulhorn, a mountain over 8,800 feet high, and standing between the Lake of Brienz and Grindelwald in Switzerland, and he concluded that the extreme upward range, or limit of the twilight, was placed 378,000 feet, or nearly seventy-one miles above the level of the sea. The problem, however, which this ingenious observer thus attempted to solve, is, in reality, of considerable complexity, and his results are therefore to be received with some reservation and caution. The twilight endures for different periods, at different times, even at the same place. The condition of the air very largely influences and modifies the after-sunset luminosity. In some states the air reflects light more readily and pertinaciously than at others, and therefore then appears luminous at greater elevations, and at longer distances from the earth. And, besides this, it must also be borne in mind that the air is at all times too rare towards its outer limit to be capable of sending back thence any luminous impression that can be distinguished by the eye. The atmosphere assuredly extends away from the earth far beyond any place at which twilight can be seen. It is, however, worthy of note that the conclusions drawn from the observations on the Faulhorn are, in a large measure, supported from an altogether different source. At the time of a lunar eclipse, when the earth advances in between the sun and the moon, so as to cast its shadow upon the lunar face, it necessarily pushes its atmospheric investment before it, and this causes a gradual shading off of the deep shadow towards its outer edge From a close scrutiny of the breadth and aspect of this softened and graduated shadow, astronomers have inferred that the denser part of the atmosphere, or the portion of it which is capable of producing a material and perceptible effect upon the passage of light, must extend, at any rate, 240,000 feet, or forty-five miles, away from the surface of the earth, a difference from the estimate formed from the duration of twilight not at all more than the discrepancy which is obviously incident to the difficulty of fixing the exact termination of either a faint glare or a faint shadow. Both series of observations are quite compatible with the now generally accepted notion that the atmosphere of the earth in reality extends considerably more than fifty miles from its surface.

The exact definition of twilight is not, however, an altogether settled matter. It was at one time conceived that twilight lasted until the sun was eighteen degrees below the horizon, and then ceased. As a matter of fact, this is an altogether unsatisfactory and illusory conception. There is sometimes a very bright twilight long after the sun has reached this depression, and at other times there is absolute darkness considerably before. Alexander

von Humboldt found that the duration of twilight was restricted to a very few minutes in the inter-tropical regions of South America. It endures a quarter-of-an-hour at Chili, and half-an-hour upon the slopes of the Eastern Alps. When the air is heavily laden with vapour, or with particles of snow, there is occasionally strong twilight until the sun is quite 30° below the horizon. The common rule-of-thumb test for the duration of twilight is the ability to perceive ordinary objects in the open air. The astronomer's estimate is based upon a more exact, and, therefore, more serviceable indication. The twilight is conceived by it to be at an end, the instant a sixth magnitude star can be seen twinkling in the sky high overhead. This, upon the whole, is perhaps as good and practical a standard as can be adopted.

But the twilight is not the only visible manifestation which this subtle aërial investment deigns to make to the eyes of man. Even during the presence of the sun above the horizon the air can be seen; the blue sky, which reveals itself as the hemispherical vault of the firmament in the absence of clouds, is the far depths of the air sending back to the observer some part of the solar illumination which they receive. The light thus returned to the eye is blue, simply because the particles of the air are of such exceedingly diminutive size that they can effectively deal with only the smallest of the luminous vibrations—that is, with the blue undulations. There are some faint and subordinate interminglings of the other coloured rays in the blue of the sky, but they are in such trifling quantity compared with the blue that they are practically swallowed up and lost in its superior abundance. They can only be detected in the preponderant flood of blue, and rendered sensible to the eye, by the subtle processes with which exact science and skilful manipulators are competent to deal. It was at one time believed that the blueness of the sky was due to the passage inwards of blue rays through the atmosphere, from which rays their yellow and red associates had been filtered off, and held back by the air particles during the passage. This view, however, is attended by the important difficulty that the light under such circumstances must be conceived to be issuing from the dark regions of space which have no ray-emitting power. The effect, obviously, must be due to the reflection of light that has emanated from the sun. Dr. Tyndall alludes to this view of the case very forcibly. He remarks, in a lucid discussion of this question, "Proofs of the most cogent description could be adduced to show that the light of the firmament is reflected light. The light of the firmament comes to us across the direction of the solar rays, and this lateral and opposing rush of wave-motion can only be due to the rebound of the waves from the air itself, or from something suspended in the air. The solar light, moreover, is not reflected by the sky in the proportions which produce white. The sky is blue, which indicates an excess of the smaller waves."*

But it so happens that there is one special and quite indisputable test to which this view of the cause of the blueness of the sky can be referred, and by which it is effectually confirmed. In the peculiar condition of light in which it is technically spoken of as "polarised," the ordinary vibrations of the rays are so modified as to limit their vibratory play to two transverse directions diametrically crossing each other. By appropriate management the undulations in either one of these directions can be quenched without at the same time arresting those which vibrate the opposite way. This condition is brought about in light whenever it is reflected from a surface of glass, at an angle of 56 or 57 degrees,† and it is then indicated, as present, by the circumstance that the ray appears to have acquired the properties of sides, by two of which it can, and by other two of which it cannot be reflected a second time. If the ray in this polarised state be examined by a prism of glass, or of transparent crystal, cut and mounted in a particular way familiar to opticians, it is found that the light is alternately quenched and renewed, as the prism is turned upon itself, at each quarter of a revolution, whilst unpolarised rays are transmitted through the prism in whatever position it may be placed.‡ Now when the blue light of the sky is examined by one of these analysing prisms, as they are termed, it is found that, at a distance of about ninety degrees of the hemispherical vault from the sun, it is alternately quenched and renewed, as the prism is turned. The blue light from that portion of the sky therefore is polarised, and consequently is light that *has been reflected*§ from something or other. But in the circumstances of the case, there is nothing that can so act upon it, but the thickly clustering particles of the air. It is only, however, the light which comes from one particular part of the sky that is affected in this way, because it is only from that

* "Lectures on Light," p. 152.

† The exact angle for polarisation with glass is 56° 45′.

‡ "Science for All," Vol. II., p. 353.

§ The angle for polarisation by reflection for air is 45°.

part that is reflected to the eye at the angle necessary for the establishment of the four-sided susceptibility. The relative positions of the sun, of the reflecting air-particles, and of the observer's eye, are then such that from that particular part the requisite angle is brought into play. But from all other points of the sky the reflection to the eye is by a different angle, and there is no polarisation. Since, however, the blue light from one part of the sky is polarised by reflection, and since the blueness is so exactly the same over all parts of the sky, it may fairly be inferred that the blue sheen of the sky is everywhere due to reflected light. In other words, the observation that the light from the sky is polarised at one part virtually confirms the assumption that the blue sky is light reflected from the thickly clustering air-particles which float round the earth, and which stretch out so far from it into space.

The gorgeous colours of the clouds, which occasionally present so beautiful a spectacle before sunrise and after sunset, depend mainly upon the circumstance that the aqueous particles which they contain are of such large size, in comparison with the dimensions of the undulations of light, as to enable them to reflect all the colour-constituents alike—the largest as well as the smallest—the coarse oscillations of the red and yellow, as well as the exquisitely delicate vibrations of the blue. As the sun sinks towards the horizon, and as the aërial distance increases, through which the rays have to pass, more air-particles of necessity lie in their path, and more and more of the less refrangible coloured rays are arrested with the augmenting length of the track; first the blue, then the green, afterwards the yellow, and finally the orange and red. Consequently, although the light reflected from the sky at noon comprises only the weak azure vibrations, that which is reflected from the vapours and clouds after sunset, may consist chiefly of the crimson rays which have made their way up through the long air-track, and which are thence thrown back to the eye. Professor Brücke has, indeed, constructed an artificial blue sky, by dropping a spirituous solution of resin into water until the liquid becomes turbid and milky. When a black board is placed behind the glass containing this turbid solution, and the light is allowed to fall upon the liquid obliquely from above, it assumes the aspect of a clear blue sky. Professor Helmholtz very unpoetically, and almost irreverently, speaks of a blue eye as simply an eye with turbid humours. Professor Tyndall has followed up this interesting branch of investigation, by showing that an artificial blue sky can also be produced by throwing a strong beam of electric light upon certain kinds of gas contained in long glass tubes. The effect, he conceives, to be in some measure dependent upon the decomposition of the gas through the agency of the light. One portion of the gas is suddenly precipitated in the condition of a delicate cloud, capable of catching and turning back the blue vibrations. In some modifications of the experiments, the attenuated vapour makes its first appearance in an exquisitely delicate form. The light reflected from these artificially-constructed blue clouds, is always polarised where it is thrown off at an angle of 90° from the course by which it has fallen upon the reflecting particles. The most perfect polarisation always occurs in the direction that is perpendicular to the path of the illuminating beam. The effect gradually grows weaker, and ultimately fades away, as this perpendicularity is departed from. The polarisation of the sky is most distinctly developed in one particular track of the blue vault, and fades gradually away as the neighbouring regions are brought successively under examination.

The gorgeous colours of the sunset-clouds are thus due to the circumstance that the yellow and red rays of light have more penetrative momentum than the blue. They make their way through stretches of the atmosphere which entirely arrest and turn back the blue, and they do this the more especially if the air is laden at the time with extraneous particles that augment the aërial opacity. When the sun is below the horizon, and streaks, or layers of clouds are hanging above it in the atmosphere, at heights which still enable them to receive illumination from the bright luminary, the red and yellow rays struggle on through the air as far as these clouds, dropping their blue associates by the way, and thus paint their fleecy surfaces with red and yellow-tinted light. The colours, that so commonly appear towards the eastern side of the sky after sunset, are virtually reflections of a secondary kind, shot off from the cloud-surfaces upon which they have first fallen, so that they ultimately strike upon other clouds in remote parts of the firmament, and are from them returned to the eye. There is also a secondary or eastern twilight, of a quite analogous nature, which faintly illuminates the remote side of the sky after sunset, and which is simply the glancing of the twilight of the west off towards the east, from the air-particles that catch the rays in the

first instance. The rosy light, which tinges so beautifully the summits of lofty snow-clad mountains, in Alpine regions, before sunrise and after sunset, is of the same nature as that which is seen in the clouds; the only special circumstance in the case is that it is a snow-covered mountain, instead of a fleecy cloud, which stands in the path of the penetrating red rays, that are making their way up from the sun. This roseate after-glow is very exquisitely exhibited by the Jungfrau, when it is

This pale ghost of the afterglow is, no doubt a mere effect of contrast. The white surfaces of the mountain, which had almost faded out of sight, are able again to rouse a visual impression in the eye when the retina has acquired renewed sensibility from the repose furnished by the darkness around. M. T. N. de Saussure adopts this explanation of the very striking and beautiful appearance to which allusion is here made, but he remarks that the pale apparition thus following the afterglow is not itself

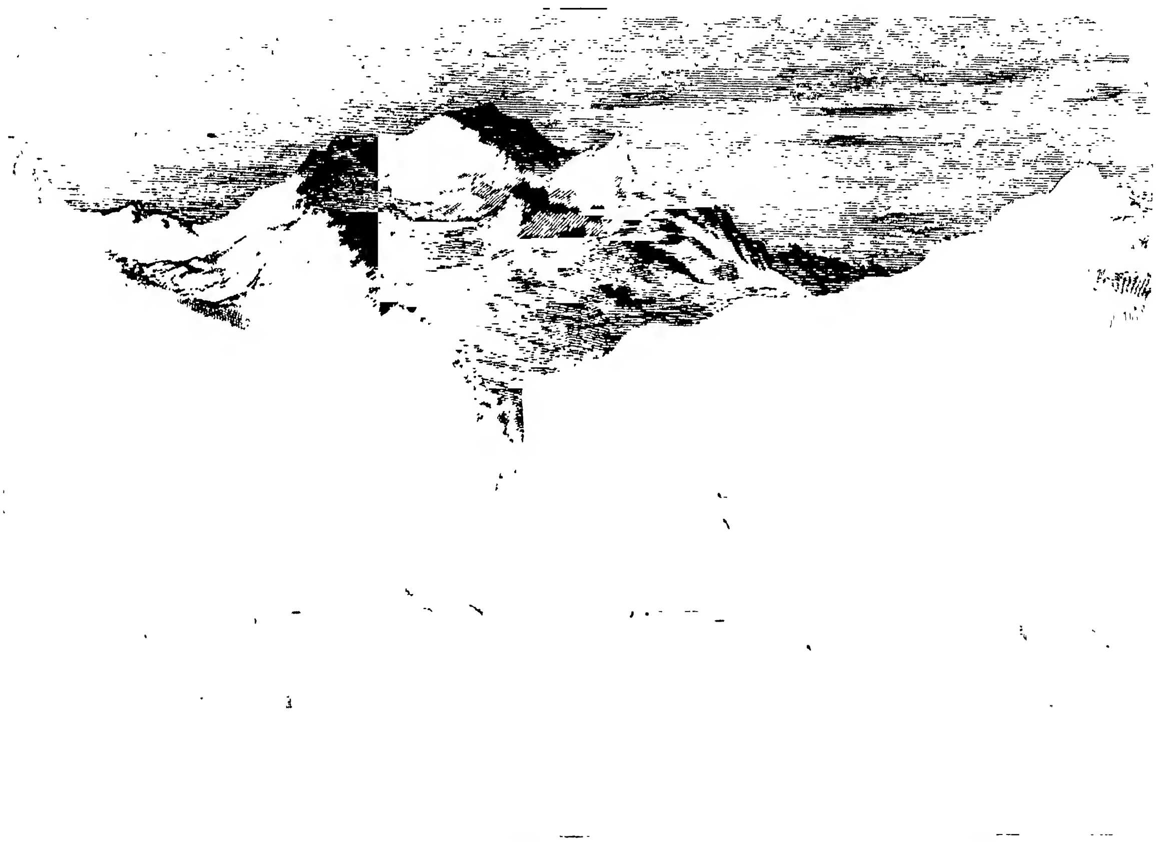

Fig. 2.—The Jungfrau seen through the mouth of the Lütschine Valley from Interlaken.

contemplated from Interlaken through the opening of the Lütschine valley, or from the mountain slopes that look down upon the sides of that gorge. The broad-based cone, with its lateral horns, or peaks, of Silver and Snow* above, and with its ample drapery of glaciers below, is suddenly covered in the deepening twilight with the crimson hue of the rose, and this then gradually and slowly fades until the whole has almost vanished into the darkness, when all at once the form of the mountain again starts out into distinct visibility, but with a weird and ghostly instead of a rosy light (Fig. 2).

* The Silberhorn and Schneehorn.

always destitute of colour. He says, "The white peaks of the Alps being first projected on an illuminated sky, and then on the shades of the earth, appear to be again coloured, although their whiteness remains the same."

M. Bravais, upon one favourable opportunity, was fortunate enough to secure from the summit of the Faulhorn, a prolonged series of observations of the way in which the several colours present themselves in succession in serene mornings during the approach of sunrise. The first tinge of colour appeared towards the east, in the form of a reddish or orange-coloured band, while the sun was still 12

degrees below the horizon. This became fringed above with yellow when the sun was only ten degrees below. When it was within eight degrees of the horizon, a greenish band was added above the yellow, and a blue tint then extended quite to the upper limit of the twilight. With the sun only four degrees from the horizon, deep purple appeared above the green, and the blue towards the zenith was also strongly tinged with green. At the same time a purple and reddish light began to reveal itself above the western horizon. When the sun was within two degrees of rising, there was a deep band of red light in the west, fringed with violet or purple above, and with the sky strongly tinted with green towards the zenith. When the solar disc just appeared above the horizon, its disc was of a yellow or orange-coloured hue, and invested with a glow of the same tints extending over the lower part of the sky. All ruddiness disappeared when the sun was two degrees, or four times its own breadth, above the horizon, but the yellow light was still pronounced, and passing into blue and green above. The last trace of colour faded away through green, when the sun was six degrees above the horizon. As a general rule the ruddy tints disappeared, and the green tints were in their strongest ascendancy as soon as the sun's disc presented itself above the horizon. Professor Kaemtz, the well-known meteorologist of Halle, considers that the green tint in such circumstances is due to the blending of the ordinary blue light of the sky with the yellow rays incident to the sunrise, and he considers that this view of the case will account for the notorious circumstance that the recently risen or nearly setting sun is never green. The weak blue rays are stopped off when the direct sunshine is passing through the dense and possibly vapour-laden layers of the atmosphere. But whenever it is one portion only of the chromatic constituents of the light that is thus filtered off, the strong yellow and orange rays are the residual parts that make their way through.

When, with an otherwise unclouded blue sky, the western horizon assumes a purple tint after sunset, this almost certainly gives promise of the prevalence of fine weather. When, after rain, the clouds are strongly tinted with ruddy light, the augury is of a like good character. A whitish-yellow glare, ensuing after the setting of a brilliant white sun, is almost certainly followed by rain. Deep ruddy tints over the eastern horizon before sunrise most generally indicate the approach of rain, whilst a grey and colourless eastern sky before sunrise gives promise of fine weather. The reason for this apparent anomaly simply is that the ruddy light is for the most part caught in the evening by high cirrus clouds, which are the clouds of a dry atmosphere, and in the morning by dense stratus clouds, which are connected with the increasing precipitation of aqueous vapour. When there is enough vapour in the air in the early morning to furnish red clouds, it is almost certain that denser clouds will gather with the advance of day.

Complete circles of faintly-coloured light are sometimes formed round the moon on nights when the sky is thinly veiled with haze. The iridescent rings in such circumstances are familiarly spoken of as lunar glories, or halos. In its most characteristic and complete state the circle has a diameter of 45° of the celestial sphere —that is, it is a ring-shaped band of light concentric with the moon's face, and just forty-five times that luminary's own breadth away from it.* The colour is generally very subdued, but it

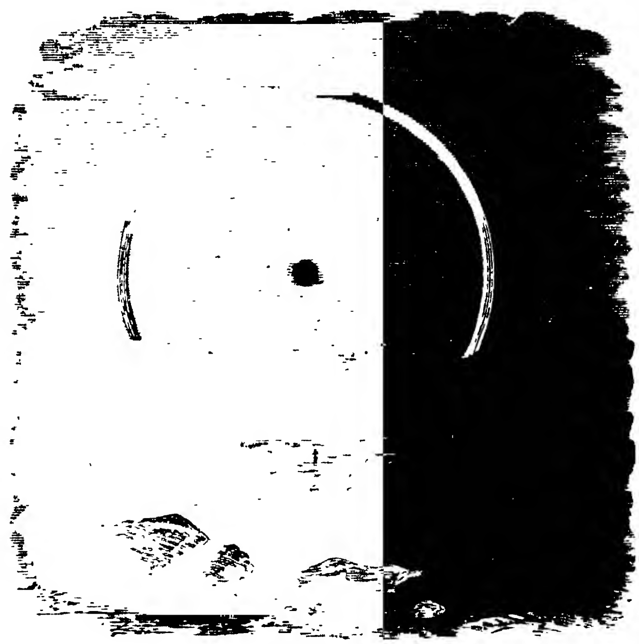

Fig. 3.—A Lunar Halo.

is occasionally so well pronounced as to render the halo liable to be mistaken by unpractised observers for a lunar rainbow (Fig. 3). The distinction is, nevertheless, absolute and clear. The halo encircles the moon, and therefore appears on the same side of the sky, whereas the rainbow of necessity presents itself on the side of the sky which is opposite to the moon. The observer stands with his face to

* The moon has an apparent diameter of half a degree.

the moon whilst looking at a halo, but must have his back to the moon whilst he is contemplating a rainbow. Circles of a similar character are occasionally formed round the sun, and they are not as easily observed on account of the overwhelming glare of the solar light. Whenever the colour is well developed it is found that there is a red tint at that edge of the luminous band which is nearest to the moon or sun, and a blue one at the opposite margin. The halo thus produced round the moon or sun is due to the influence of minute prism-shaped crystals of ice, floating in great abundance in the higher regions of the air. There are few readers of these pages who are not aware that if a sunbeam is allowed to fall upon a three-sided bar, or prism of glass, it is bent out of its original course as it passes through the prism, and, at the same time, broken up into a diverging sheaf of coloured rays.* The ice-prisms, which float suspended in the upper regions of the atmosphere, exert a similar influence upon the light that passes amongst them.

When an observer is looking at a halo encircling the moon, in order to understand what is taking place, he must endeavour to conceive that, at the distance of 23 deg. from the apparent position of the moon, the ice-prisms stand in such a relation to the light which is thrown off to them from the shining surface of the luminary, as to bend down towards the eye a comparatively large proportion of the rays. A very considerable number of the ice-prisms, which happen to lie at that precise distance, are so ranged as to conspire to throw the luminous beams towards the eye, rather than in any other direction; and, as this takes place at the same distance all round the moon, the luminous band appears as a ring. The ice-crystals are scattered in the air in all conceivable positions. But, in consequence of the particular form of the crystals and of the special power of that form over the vibrations of light, only those which occupy the specified distance and range deal with the rays in this way. The reason for this result is, perhaps, one which can hardly be explained satisfactorily in familiar and unmathematical language, but it is connected with the circumstance that, in certain specific positions, the movement of a prism exerts less bending upon transmitted rays than it does in others. That such is the case may be experimentally proved if a prism of glass is turned round upon itself, when a sunbeam is falling upon it. The divergence of the beam from its original course is then seen to alter with the revolution of the prism, but, in one particular position, it takes more turning of the prism to produce any given amount of deviation. A great number of the ice-prisms that are placed where the halo appears in the sky, are in that position, on account of the relation in which they stand to the moon and the eye, and conspire to produce the luminous band. The size of the circle of the halo is determined by the fact that the emergent light issues from the terminal face of each prism at a fixed, definite angle. The halo most commonly seen has, as has been already said, an apparent diameter of 45°. But halos of rather more than twice this diameter are occasionally produced. In such circumstances the light is more faint, and it is almost always devoid of colour. In these instances the light issues from the prisms at an angle of 46° of deviation from its original course, and this larger deviation appears to be due to the rays being emitted from the ends of the prisms rather than from their sides, and where the end and side meet each other perpendicularly.

The so-called "coronas" of coloured light, which are at times formed about the moon and sun, are of a quite different character to halos (Fig. 4). In the first place they are of a much smaller size. They are, for the most part, not more than four times the breadth of the luminary, away from its rim. Their apparent diameters are comprised within a range of from two to four degrees.

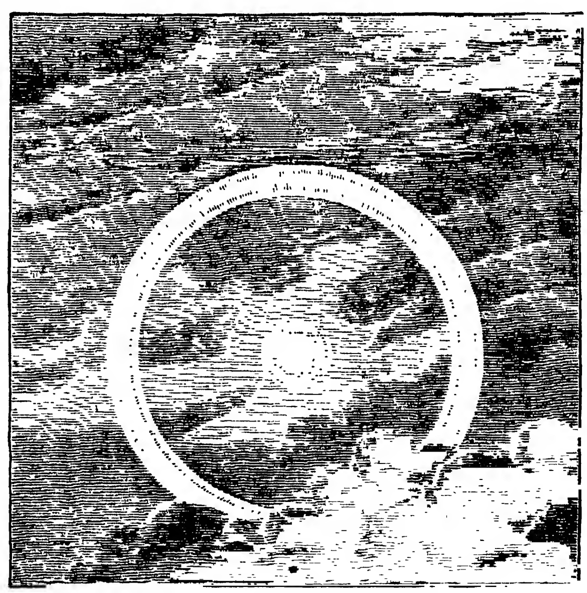

Fig. 4.—A Corona round the Sun.

They are also distinguished from the halos by a yet more definite mark. The order of the succession of colours is reversed. The red presents itself

* "Science for All," Vol. I., p. 192.

at the outer border of the circle, and the blue at the inner rim, which is the ruddy side in the halo. The corona in reality is the offspring of mist rather than of frost; it is generated by the aqueous vapour floating in the air between the sun or moon and the observer. It is of the same order of appearances as the coloured rings produced upon the windows of carriages, bedewed with moisture, when bright lights are looked at through them. A similar circle of iridescence can, at any time, be artificially caused to present itself by contemplating the flame of a lamp, or candle, through a piece of plate-glass upon which the minute spherical spores of club-moss have been dusted, or by looking at the bulb of a mercurial thermometer shining brightly in the sun, through a narrow slit cut in stiff paper by the point of a penknife.

The colours exhibited in the corona are of the same nature as the phenomena known to opticians as "diffraction fringes." They are caused by interferences set up amongst the constituent vibrations of the light-beams as these glance past the spherules of mist. They are physically allied to the iridescence produced upon pearl buttons by the striæ of their surface, or by lines traced very closely together upon glass by the diamond, and to the coloured bands which are often noticed upon windows soiled with smoke and dust.

Coronal rings are less frequently observed about the sun than they are about the moon. But this is only because they are more easily overlooked when they occur in the midst of the glare of bright sunshine than they are in soft moonlight. They may be very commonly detected in connection with the sun, if the eye is screened from the overpowering glare by darkly-coloured or smoked glass. At times two, or even three, circular bands may be seen surrounding each other, and the second and third circles are then at the same distance from each other, and from the first, that the first is from the sun. Professor Kaemtz has given an account of one very remarkable case in which as many as eight concentric circles were formed, the first three being blue, white, and red, and those which followed in the outward order of succession being purple, blue, green, yellow, and red, thus obviously constituting a second series, as the transition in the same direction was again from blue towards red. When a corona is visible round the sun, its colours are more brilliantly developed than they are in connection with the moon. The head of the Spectre of the Brocken, which is merely the shadow of a human figure cast upon mist,* is sometimes surrounded with a circular glory of coloured light. This, in such circumstances, is simply the chromatic fringe developed by diffraction at the margin of the dark shadow. The so-called "Fog-image"† of the Rigi Kulm, and of other elevated parts of the Swiss mountains, is essentially of the same nature.

Halos invariably occur in some form of cirrus, which is properly the ice-cloud. The coronas, on the other hand, as commonly present themselves in the cumulus variety of cloud; but all clouds, excepting the ice-clouds, are capable of producing them, provided they are not too dense to permit the passage of red light. Lunar halos, as a rule, present themselves when the barometer is falling, and when the cirrus cloud is thickening into cirro-stratus; they are, therefore, correctly regarded as harbingers of rain. The corona is not so much a weather sign in itself as the halo, but it becomes so in the changes which it is liable to undergo after its first formation. The circle is of a less diameter when the mist-spherules are large than it is when they are small. The corona consequently contracts gradually in breadth as the deposition of moisture becomes more copious. A contracting corona hence indicates the approach of rain, whilst an enlarging corona, on the other hand, gives promise of fine weather. Coronas round the sun are, however, scarcely as significant of changes in the weather as those which appear about the moon, because they are liable to be produced in all kinds of vesicular clouds which are not too dense for the passage of the stronger vibrations of light.

* "Science for All," Vol. III., p. 349.

† The Nebenbild of the German meteorologists.

STONE-LILIES AND FEATHER-STARS.

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THE stone-lilies have been already referred to in these pages as belonging to a somewhat varied assemblage of animal forms, which may be described by the general term of "limestone-builders." It has been pointed out * that many limestones consist almost entirely of the remains of these beautiful animals, which are known to naturalists as Crinoids. The Greek word *krinon* means a lily; and long before the adoption of the term Crinoidea for this class of animals, the name Encrinites—in which the same root is traceable—was employed to describe their fossil remains. The earliest author who systematically treated of these remains was the celebrated Agricola (A.D. 1530), though, from the manner in which he speaks of them, it is evident that they had long attracted the attention of naturalists, and that the names *Trochites*, *Entrochus*, and *Encrinus* had found their way into general use.

The first was applied to the separated stem-joints, which have since been known as "St. Cuthbert's beads," a name † familiar to the readers of "Marmion." *Entrochus* was used to denote a larger piece of stem, consisting of several united joints, such as one may find without difficulty in the limestones of Clifton Down, Wenlock Edge, and elsewhere. The last name, *Encrinus*, was applied to the really lily-like remains, which consisted of a cup supported on a stem, and giving off ten or more arms. This name has gained a permanent place in scientific nomenclature, as denoting one particular genus of the fossil Crinoidea, the commonest species of which is the well-known "Lily-encrinite," from the Trias ‡ of Germany (Fig. 1).

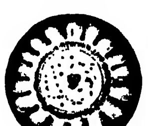

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Fig. 1.—The Lily Encrinite (*Encrinus liliiformis*). *a*, Surface of a Stem-joint.

The mutual relationship of the three kinds of fossil remains mentioned above was not recognised till more than a century after the time of Agricola, and even then their real nature was misunderstood. Fossil Crinoids were described as "certain stones figured like plants, and by some observing men esteemed to be plants petrified." Another writer speaks of their remains in the Carboniferous Limestone § of Somersetshire as "rock-plants growing in the lead-mines of the Mendip Hills." Observing men, however, did not altogether agree as to which way up these rock-plants grew; for while some authors believed the body or cup of the Crinoid to be the base of the stem, and regarded the arms as radiating and subdividing roots, others considered that the more or less branching roots of the pear-encrinite (Fig. 7) really belong to the body, and not to the lower part of the stem. By other writers the cups were taken for petrified flowers or fruits, and the stems thought to be the back-bones of fishes.

The credit of pointing out that the Crinoidea, far from belonging to the vegetable kingdom, are true animals, closely approximating in structure to the existing types known as sea-stars, || is due to our countryman, Edward Llhuyd, who was keeper of the Ashmolean Museum at Oxford at the end of the seventeenth century. Not only did he refer these remains to the same group with the sea-stars, but he even pointed out the feather-star (Fig. 2) as the particular form of sea-star to which the fossil Crinoidea are most closely allied.

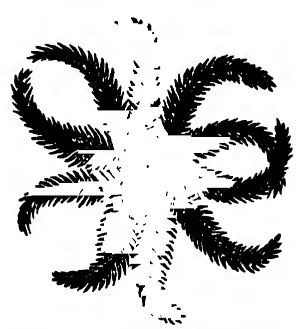


Fig. 2.—The Rosy Feather-star (*Comatula rosacea*).

The feather-star (Fig. 2) differs considerably from the other star-fishes, both in its external appearance and in its mode of life. As in the Echinoderms ¶ generally, there are five rays, corresponding to the five arms of the star-fish; but each of these five rays may fork from one to seven times, so that the number of arms sometimes reaches two hundred or more.

* "Science for All," Vol. I., p. 11; Vol. II., p. 163.

† "A Star-fish and its Relatives:" "Science for All," Vol. III., p. 305.

‡ For the positions of these geological formations in the crust of the earth, see the Frontispiece to Vol. I. of "Science for All."

§ See Frontispiece to Vol. I., "Science for All."

|| "Science for All," Vol. III., p. 300, Fig. 1.

¶ *Ibid.*, Vol. III., p. 303.

In those of our own seas, however, such as the rosy feather-star (Fig. 2), there are rarely more than ten arms. These arms are supported by an internal skeleton of limestone joints placed end to end, and are closely fringed with smaller jointed appendages, which spring from them like the barbs from the quill of a feather. This feature sufficiently accounts both for the popular and for the scientific names (*Comatula*) of this animal. Readers of the paper on "The Star-fish and its Relatives," to which reference has been made already, will remember that the ordinary star-fishes, brittle-stars, and sea-urchins live with their mouths downwards, and crawl about on the sea-bottom in search of food by the aid of their numerous sucking feet. The feather-star, however, lies on its back, with its mouth upwards, and has a number of little jointed hooks fixed in the middle of its back, by which it can anchor itself to stones and sea-weeds. It detaches itself occasionally, and swims about for awhile with a peculiarly graceful alternating movement of its arms, eventually settling down again in its previous position. The mouth is in the middle of the upper surface of the body, and the arms are spread out around it. On the upper surface of each arm is a groove, which is lined by a vast number of those delicate little protoplasmic filaments that are known to naturalists as cilia.* The continued vibratory movement of these cilia produces currents in the water that carry tiny food-particles towards the mouth, where the grooves of all the arms meet (Fig. 3, B).

It must be remembered that Llhuyd's determination of the fossil stone-lilies as allied to the recent feather-stars was made without any knowledge of the fact that there are such things as living stone-lilies. The first of these known to science was not discovered till fifty years after Llhuyd wrote, and even then its true nature was misapprehended. Eminent naturalists, like Linnæus, Lamarck, and Cuvier, considered these recent sea-lilies as zoophytes,† allied to the sea-pens, sea-firs, sea-shrubs, and the clustered sea-polype, while the feather-stars were thrown back again by them among the other star-fishes. It was not till the year 1821 that Mr. Miller, a German naturalist, residing in Bristol, showed clearly that the feather-star is essentially similar to one of the old stone-lilies or to a recent sea-lily, except that it has no stem. The general structure and the mode of life are identical in both. Figures of two recent sea-lilies (*Rhizocrinus*, *Pentacrinus*) have been already given.‡ The *Pentacrinus* is the type which was first known to science, one having been brought over from the West Indies by a French naval officer in 1755, and placed in the museum of the Jardin des Plantes, at Paris, under the name of "Palmier Marin." This West Indian species (*Pentacrinus Caput-Medusæ*), which is represented in our Fig. 3, differs considerably from the *Pentacrinus maclearanus*, which was dredged by the *Challenger* from the depths of the Atlantic, and named after one of the officers on board by Sir Wyville Thomson. For more than a hundred years after the first *Pentacrinus* was brought to Europe, these beautiful animals were excessively rare. Even as late as the year 1865, as much as £50 was paid for a single specimen. But the systematic exploration of the bed of the ocean by the dredging

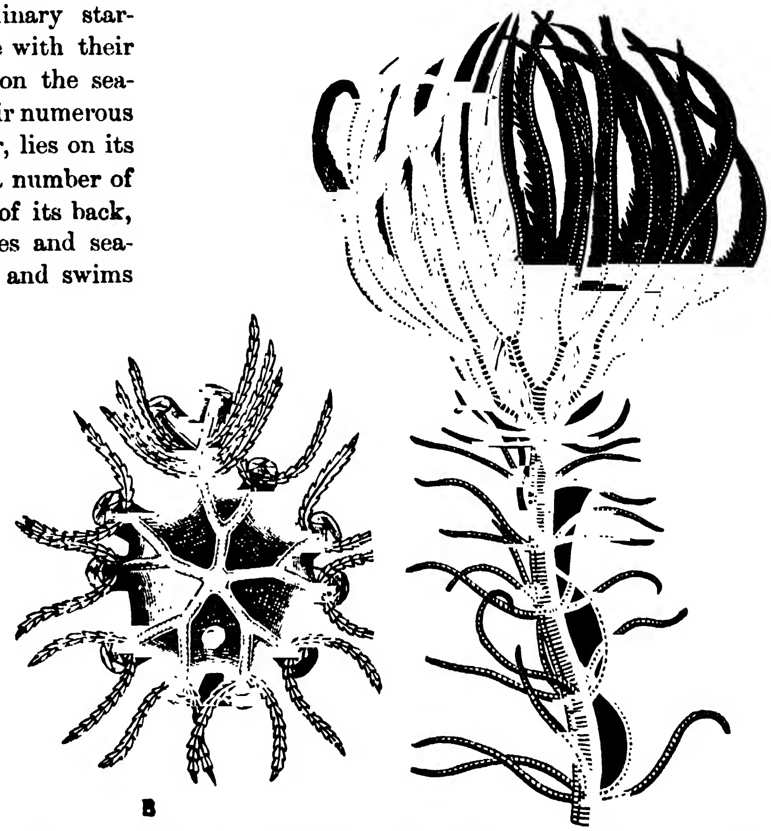


Fig. 3.—Pentacrinus Caput-Medusæ. (*About One-half Natural Size.*) A, Side View; B, View of Ventral Disc from above, showing the Food Grooves converging to the Mouth.

* "Science for All," Vol. I., p. 59; Vol. II., p. 374

† *Ibid.*, Vol. I., p. 378; Vol. II., pp. 207, 312—316; Vol. IV., p. 81.

expeditions of England, America, and other countries has made them more abundant in collections, though not the less beautiful. They live in great forests on certain parts of the sea-bottom, sometimes attaching themselves to telegraph cables. In other kinds, however, such as *Rhizocrinus*,* the stem ends below in a spreading root, and so fixes the animal in the ooze which covers the ocean-bed.

Like the feather-stars, they live with the mouth upwards, and the branching arms spread out so as to catch as many small particles as possible in the currents which sweep down the food-grooves towards the central mouth (Fig. 3).

Fig. 4.—Young of the Rosy Feather-star (*Comatula rosacea*) in the Stalked, or Pentacrinoid Stage.

The relationship between the feather-stars and the stalked sea-lilies is still closer than was imagined by Llhuyd and Miller; for the young feather-star is not free like its parent, but grows on a stem (Fig. 4), from which it eventually detaches itself. In this stage of its development it is known as a Pentacrinoid, a name which expresses its resemblance to the permanently-stalked *Pentacrinus* (Fig. 3). This curious fact was discovered by Mr. J. V. Thompson, and was confirmed five years later by the late Professor Edward Forbes, who was fortunate enough, when dredging in Dublin Bay, to find numbers of the Pentacrinoid young of the rosy feather-star in a more advanced stage than any that had ever been seen before. Some of them, indeed, were so far advanced that Professor Forbes was actually able to "see the creature drop from its stem and swim about, a true feather-star." The severance occurs between the second stem-joint and the top one, which becomes an important part of the mature animal, for it bears the hooks by which the animal is able to fix itself to sea-weeds, zoophytes, &c. In some cases as many as thirty of these hooks may be developed before the animal parts from its stem and commences its new mode of life.

The gradual development of the stem is a very interesting process. The young of the feather-star leaves the egg as a little oval body about $\frac{1}{30}''$ in length, shaped somewhat like a small barrel, and surrounded by four hoops of long vibratile cilia, with a still longer tuft of them at its hinder end (Fig. 5, *a*). By means of these cilia it swims about in the water. After a while, slender limestone rods make their appearance near the front end, where the temporary mouth is situated, and by repeated forking and joining these rods give rise

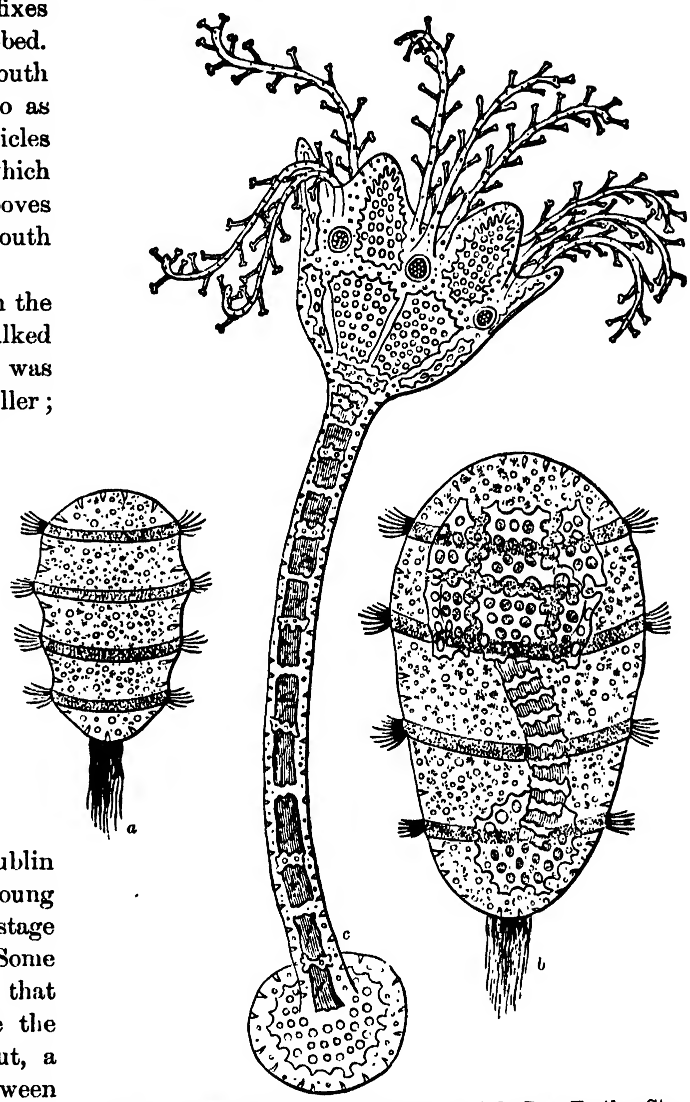


Fig. 5.—Three Stages in the Development of the Rosy Feather-Star.
a, Larva just Hatched; *b*, Larva with Rudiments of Limestone Plates: *c*, Pentacrinoid Larva. The Mouth is in the Centre of the Ring of Tentacles, but no traces of Arms are yet Visible.

to ten plates of a delicate limestone network, which are arranged in two cross rings of five plates each (Fig. 5, *b*). Passing backwards from beneath the centre of the lower ring of plates is a series of delicate rings of limestone, which become supported, later on, by bundles of longitudinal rods forming inside them. The last of these bundles, at the hinder end of the larva, rests against a circular plate of considerable relative size. At this stage the larva has the form of a bent club or

* "Science for All," Vol. III., p. 163.

rod, with an enlarged head. The ciliated bands disappear, and it gradually loses its power of swimming, attaching itself to some stone or other solid substance by its base, the knob of the club being free (Fig. 5, *c*). This knob gradually becomes the body of the future feather-star, while the series of rings between it and the base of attachment develop into the elongated stem-joints of the Pentacrinoid. The enlarged head gradually becomes five-lobed, each lobe being supported by one of the upper rings of plates, and after a while the lobes separate like the petals of a flower, so as to expose between them the opening of the permanent mouth. Around this mouth are five groups of three tentacles each, delicate tubular organs, which spring from a ring-shaped water-vessel* in the lip.

The arms, which at this stage are quite undeveloped, now begin to make their appearance, sprouting outwards from between the two rings of plates, the upper one of which gradually disappears. Clawed hooks are pushed out from the enlarged uppermost stem-joint, which eventually separates itself from the rest of the stem, as described above.

The general anatomy of a feather-star or sea-lily is essentially the same as that of a common star-fish, allowance being made for the different position of the mouth in the two cases. Immediately within the ciliated groove of the Crinoid arm runs a nerve-cord, just as in the star-fish. Deeper still lies a blood-vessel, and then the water-vessel, which is relatively smaller and less important than in the star-fish; for the water-vascular system of the Crinoid takes no part in effecting the movements of the animal, like that of the star-fish does. Being more or less permanently fixed on its back, with its mouth upwards, ready to take anything that comes in the way of food, the Crinoid has no need of sucking feet to help it in moving about. But these organs, which are so important to the star-fishes and urchins, are replaced in the Crinoids by excessively delicate little tubes, the tentacles, in which the work of breathing seems to be carried on, oxygen passing through their walls from the water around them into that which they contain. All the water-vessels of the arms are lined by cilia, and communicate, like those of the star-fish, with a ring-vessel situated in the lip around the mouth. There is, however, a less direct communication between this vessel and the external water, as is effected by the stone-canal of the star-fishes and urchins. But water is able to enter the body-cavity through innumerable small tubular openings in its walls, which are lined by cilia, all working inwards; some of these lead into the water-vascular ring, which is also in free communication with the body-cavity by means of similar openings in its floor, so that it communicates readily with the exterior.

Here in the Echinoderms, therefore, we meet with an excellent illustration of a principle which is largely exemplified in the other sub-kingdoms of the animal world. There is one fundamental plan, according to which the various members of each sub-kingdom are constructed, but the details of this plan are worked out in different ways in the different classes of animals which together make up the sub-kingdom.†

Neither the feather-stars nor the Pentacrinites can be said to enter largely into the formation of limestone, though there are some beds in the chalk of Bohemia which contain great quantities of the remains of the former. In certain parts of Germany there is an earthy bed of limestone a few inches thick which is almost entirely made up of isolated joints of the stems, arms, and pinnules of Pentacrinites, collected together in enormous numbers. Here and there, too, both in this country (as at Lyme Regis) and abroad, large slabs of shaly limestone are found containing collections of fossil Pentacrinites, some of them very perfect, and remarkable for the great length of their stems. One specimen, found in Germany, has a stem the total length of which, as measured by its broken pieces, was found to be seventy feet, while others with stems fifty feet long are not uncommon. They must have presented a curious sight in their native seas, each with its long stem, on which was the crown of arms, not more than ten or twelve inches across when fully expanded. The naturalists of the *Blake* Expeditions in the Caribbean Sea succeeded in keeping some Pentacrini alive for two hours after their removal from the dredge. This was effected by "deluding the animals into the idea that they were in their native temperatures by putting them into ice-water." Previously to this, during the Hassler Expedition of 1872, the late Professor Louis Agassiz was fortunate enough to be able to keep a little *Rhizocrinus* ‡ alive for ten or twelve hours, and he thus described what he saw:—"When contracted, the pinnules are pressed against the arms, and the arms themselves shut

* For the explanation of this term, see the article on the Star-fish, "Science for All," Vol. III., p. 300.

† Compare "Science for All," Vol. I., p. 330; Vol. II., p. 41; Vol. III., pp. 145, 274, 300.

‡ "Science for All," Vol. III., p. 163, Fig. 1.

against one another, so that the whole looks like a brush made up of a few long coarse twines. When the animal opens, the arms at first separate without bending outside, so that the whole looks like an inverted Pentapod; but gradually the tip of the arms bends outward as the arms diverge more and more, and when fully expanded the crown has the appearance of a lily of the Lilium Martagon type, in which each petal is curved upon itself, the pinnules of the arms spreading laterally more and more as the crown is more fully open. I have not been able to detect any motion in the stem traceable to contraction, though there is no stiffness in its bearing. When disturbed, the pinnules of the arms first contract, the arms straighten themselves out, and the whole gradually and slowly closes up. It was a very impressive sight for me to watch the movements of this creature, for it told, not of its own way only, but at the same time afforded a glimpse into the countless ages of the past, when these Crinoids, so rare and so rarely seen nowadays, formed a prominent feature of the animal kingdom. I could see, without great effort of the imagination, the shoal of Lockport teeming with the many genera of Crinoids which the geologists of New York have rescued from that prolific Silurian deposit, or recall the formation of my native country, in the hill-sides of which, also among fossils indicating shoal-water beds, other Crinoids abound, resembling still more closely those we find in these waters." Had Professor Agassiz been an Englishman, he would have referred to the Wenlock limestone,* and to the Carboniferous limestone of Somersetshire, instead of the Silurian shales of Lockport; while he would have spoken of the Bradford clay and its pear-encrinites (Fig. 7) instead of the Jurassic Crinoids of Switzerland. The limestone of Wenlock Edge is of approximately the same geological age as the Lockport beds of America, and is very largely composed of the remains of Crinoids and corals. In some parts of it the Crinoids are so abundant that it is spoken of as a Crinoidal limestone. Portions of this or of similar limestone-beds are exposed at Dudley, Walsall, Woolhope, and Aymestry. That at Dudley is very rich in Crinoidal remains, and is the chief source of our museum specimens.

Ages after the close of the Upper Silurian period, Crinoids again played a very important part in the formation of a limestone. The great deposit of Carboniferous limestone which underlies the coal measures in South Wales and in Somersetshire is more than two thousand feet thick, and so highly fossiliferous that the whole of it may be said to have once formed parts of animals. The lowest five hundred feet of it consist chiefly of Crinoidal remains. In all parts of Europe where Carboniferous limestone occurs it is largely made up of the skeletons of stone-lilies. They are especially abundant in Belgium, in the neighbourhood of Liége, and are also very numerous in the Carboniferous series of America, as has been well described by Professor Dana. He has pointed out how there was a long period of limestone-making both in Europe and in America before any of our coal-plants † began their work of "bottling up the sunlight" of ages now long past. There is proof, therefore, of the wide extension of the same geographical conditions, viz., an extensive submergence of the continental lands, as a prelude to the period of emergence and terrestrial vegetation that followed.

In the first half of the Upper Silurian there was a period when a sea, profuse in life, and thereby making limestones, covered a large part of the interior continental basin of America, *i.e.*, the region between the Appalachians and the Rocky Mountain chain. The same conditions were repeated in the early part of the Devonian age, and, again, in the Carboniferous there was a similar clear and open Mediterranean Sea, and limestones were forming from the relics of its abundant population.‡ In the Upper Silurian period the living species were of a miscellaneous character, Brachiopods or lampshells,§ Crinoids, and Corals occurring in nearly equal proportions; but in the Devonian period Corals were greatly predominant, and in that of the Carboniferous Crinoids had as remarkable a pre-eminence. The most prolific locality for Crinoids in America is Burlington, in the State of Iowa. More than three hundred and fifty species have been found there, many of them in the most beautiful state of preservation.

These stone-lilies, which bloomed in the ocean depths when the earth was younger and our coal not yet formed, differ very considerably from the *Pentacrini* which inhabited the Liassic Seas,|| together with the "great sea reptiles," and have survived until the present time. In most of the older Crinoids the mouth was not on the external surface of the body, for it was covered in by a

* "Science for All," Vol. II., p. 163.

† "Science for All," Vol. I., pp. 87, 88.
‡ *Ibid.*, Vol. III., pp. 46, 47.
§ *Ibid.*, Vol. I., p. 67, Fig. 5.
|| *Ibid.*, Vol. II., pp. 138, 139.

dome of rigid heavy plates (Fig. 6). But there were food-grooves on the arms, just as in the recent sea-lilies and feather-stars, and at the circumference of the dome were a number of openings, one for each groove, through which the food particles passed on their way towards the mouth.

Fig 6.—Calyx of *Actinocrinus Koninckii*, a Palæozoic Stone-lily. Round the Edge of the Dome are seen the Openings by which the Currents, sweeping down the Food Grooves of the Arms, reached the Concealed Mouth.

The earliest representative of the more modern type of Crinoid in which the mouth is open to the exterior is the "Lily Encrinite" (Fig. 1), from the Trias of Germany, a very elegant and well-known species. In an old German book about the natural history of Altenburg, dated 1774, it is recorded that the Emperor of Germany once offered a hundred thalers for a good specimen of this stone-lily attached to its stem, and free from the matrix in which it had been embedded.

At the close of the period of the Trias there commenced the formation of the great Jurassic series, that takes its name from the Jura Mountains, where it is especially well-developed. In the earliest member of it that occurs in this country, viz., the Lower Lias of Lyme Regis,* we find the oldest representative of the *Pentacrinus* type. It has persisted ever since, living in the Jurassic and Cretaceous seas, and is now represented by several species which inhabit the Caribbean Sea and the median depths of the Atlantic and Pacific. In some localities they must be remarkably abundant, for during the cruise of the *Blake* in the Caribbean Sea, no less than one hundred and twenty-four specimens were captured by one "haul" of the dredge and its appendages.

Above the Lias formation is that of the Oolites, the lowest beds of which (Inferior Oolite of Gloucestershire) contain the remains of the oldest British feather-stars. Somewhat younger still are the "Pear-Encrinites," which are so abundant in the Bradford clay (Fig. 7). In these Crinoids the body was considerably swollen, and the base of the long stem furnished with a number of roots, which served to fix the animal in the ooze covering the sea-bottom. The pear-encrinites are represented in the chalk by a dwarfed and degraded type, which has long been known as the "bottle-encrinite." It has been already pointed out that this degeneration was perhaps due to the reduced temperature of the Cretaceous seas,† for it has continued since the time of the chalk formation, and has resulted in the appearance of the little *Rhizocrinus* that is so widely distributed over the Atlantic sea-bed. The pear-encrinites seem to have fared worse during these bygone ages than the *Pentacrinus* type did, for the recent *Pentacrinidæ* resemble their ancestors much more than *Rhizocrinus* resembles the pear-encrinite. They are, however, smaller and less completely developed than the long-stalked forms of the Liassic seas.

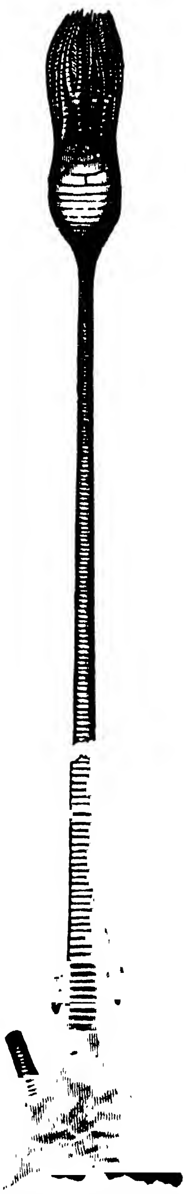


Fig. 7.—A Pear Encrinite (*Apiocrinus Roissyanus*.)

The feather-stars of the present day also seem to be smaller than their predecessors which lived in the Jurassic and Cretaceous seas. Unlike the stalked Crinoids, which are almost entirely limited to deep water, they flourish best in the shallower waters nearer land, though small and poorly-developed specimens have been dredged at nearly 3,000 fathoms. Their geographical distribution is very extensive, as they range through nearly every part of the Atlantic and Pacific, from 82° N. Lat. down to Heard Island in the Southern Sea. They are largest and most varied in the tropics, particularly in the shallow water about the West Indies and Philippine Islands, and in the Malay Archipelago. It is especially in the two latter localities that they reach their highest degree of development, some forms having not far from two hundred arms. The large feather-star of the Arctic seas, although rivalling these giants in the "spread" of the arms, possesses only ten of these organs, and is therefore much simpler in its construction than they are. It must be said that we know very little about the fossil feather-stars in this respect, as the arms are so rarely preserved, but their bodies were larger on the whole than those of existing species.

* "Science for All," Vol. II., p. 138.

† "Science for All," Vol. III., pp. 162—167.

VOICE.

By F. Jeffrey Bell, M.A.,
Professor of Comparative Anatomy in King's College, London.

When we roughly strike a board, the shaking so produced causes the particles of which the air is made up to strike more or less roughly and irregularly against one another. We make a *noise*, and we hear that noise because the jumbling of the air-particles is conveyed to the tense membrane, which, set in motion, affects the more internal parts of our ear. If, however, we regularly set in motion, as with the bow of a violin, a cord or wire tightly stretched, we produce, not an irregular or confused *noise*, but a definite and a perhaps more or less musical *sound*. But the delicate cord will give but a feeble sound; to make it more loud we have to connect with the cord a piece of wood, which, larger in size, has a greater effect on a larger volume of air.

What, then, we hear is due to a movement in the air surrounding us, and these movements of the air are most easily produced by setting a cord or a piece of wood in movement. The essential matter is the movement of the air, and this can be effected in yet another way. If air be blown down a pipe, or a straw, which has at the opposite end a free "tongue," or piece, which vibrates with the air, and itself affects the surrounding air, then we get a musical note which varies with the length of the pipe and its construction (Fig. 1).*

Fig. 1.—Straw, with Tongue. (*After Tyndall.*)
r′ r, Vibrating Reed; rs, Pipe.

In its essence, the human organ of voice is a reed-pipe of this kind, as the following anatomical description will readily show. It is conveniently situated for its purpose, inasmuch as a blast of air can always be driven through it from the lungs; for it is situated at the top of the windpipe (*trachea*), which is the channel by which air passes into and out of those organs. Consisting, as it does, of a number of cartilaginous pieces, freely movable on one another, it is, in its essential parts, represented more simply in so lowly an animal as the frog, where there are but two distinct pairs of cartilages, with which is connected, one on either side, a fold of membrane with a free edge. This free edge is set in vibration by the column of air, and gives rise to the frog's croak. To these folds we apply the term of *vocal membranes*, and the slit between them is the *glottis.*

Of the cartilages, the most prominent, and perhaps the only one of which the reader has at present any knowledge, is that which forms the Adam's apple, the *thyroid*, or shield-shaped cartilage, of technical anatomy; the large piece in the middle line of the throat which becomes so much larger as the "piping schoolboy" shoots up into the young man. This Adam's apple consists of two flattened pieces, which unite in the middle line at an angle with one another, and the extent to which the "apple" is visible is, of course, dependent on the sharpness of the ridge thus formed (*a*, Fig. 2). Above and below, each outer angle of the two wings of the thyroid cartilage gives rise to projecting processes, or horns; two superior (*c*, Fig. 2), which are a little larger than two inferior (*d*, Fig. 2). Two pairs of cartilages form the chief part of the back wall of the larynx. The ring-shaped *cricoid* cartilages have their narrow side (*f*, Fig. 2) lying below the lower edge of the thyroid, and here they are jointed to the lower horns of the thyroid cartilage; behind, this ring-shaped body is much deeper, four or five times, indeed, as deep as in front. With the upper edge of the hinder border we find two small cartilaginous pieces connected, which, from a somewhat fanciful resemblance to a ladle, have been denominated the *arytenoid* cartilages (*g*, Fig. 2). Leaving for a moment the other smaller cartilages, and only stating that they, together with those already mentioned, are connected together by ligaments, and move on one another by means of a special system of muscles, let us look at the larynx itself from inside. The figures which illustrate this are taken from the work of Dr. Czermak, and represent the arrangement of the parts of his own

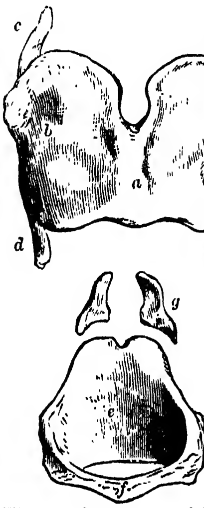


Fig. 2.—Cartilages of Larynx. (*After Quain and Sharpey.*)
b, Lateral Portion of Thyroid; e, Hind Portion of Cricoid.

* "Science for All," Vol. II., p. 296; Vol. III., p. 93.

larynx. Here we may for a moment turn aside to remark that, so far as the organ of voice is concerned, "some power" has the "giftie gi'en us to see ourselves as others see us;" for physiologists, and prominently among them the illustrious observer just mentioned, have succeeded in bringing to a high degree of completeness the process of what is called "autolaryngoscopy."

In Fig. 3, A, we see *z* marking the base of the tongue; *e*, the overhanging cartilaginous *epiglottis*, which, during the act of swallowing, closes over the *glottis*, and prevents our food from "going the wrong way;" *s*, *s* mark the small *cartilages of Santorini*, which are connected with the top of the arytenoid cartilages (*a*, *a*) and have between them the narrow slit of the glottis; *ph* marks the hinder wall of the pharynx. In Fig. 3, B, we see the slit of the glottis widely open, and now the vocal cords are themselves exposed to view, the letters *o*, *sb* pointing to the upper, and *u*, *sb* to the lower vocal cords. The former, or superior pair, are called the false vocal cords, inasmuch as it is not they, but rather the inferior pair which are the direct cause of that vibration of the air which results in the *voice*. They can best, perhaps, be understood by being regarded as the roof of the sinus, or *ventricle* (*M. v*), which is interposed between them and the vocal cords proper. These last, in addition to being folds of mucous membrane, have their substance strengthened by ligaments and muscles.

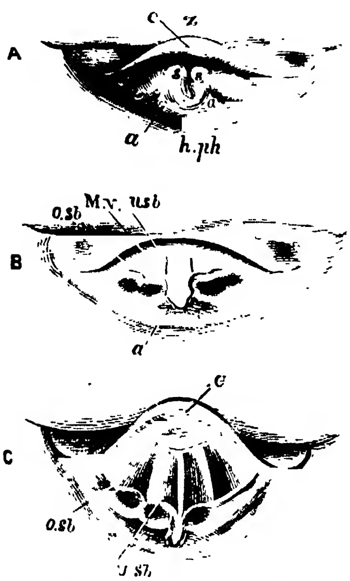


Fig. 3.—Figures of Larynx. (*After Czermak.*)

It must now be obvious that the chief problems with which we have to do are concerned with the relative positions of these vocal cords, how they may become so set as to respond to the blast of air driven through them, and how they may so vary in length as to give out different sounds. First, then, we must know to which of the movable cartilages of the larynx the vocal cords are attached. In front, as might be supposed, they are connected with the thyroid cartilage, while behind they meet the arytenoids. As the anterior ends of the cords are closer together than the posterior, it follows that when the whole apparatus is at rest, the aperture of the glottis is V-shaped (*see* Fig. 3, B). Now, as a matter of fact, when acute sounds are being produced, the slit is much narrower (Fig. 3, C), and the edges of the vocal cords lie parallel to one another; obviously, then, one of the most important changes must consist in an alteration of the position of the hinder or arytenoid cartilages.

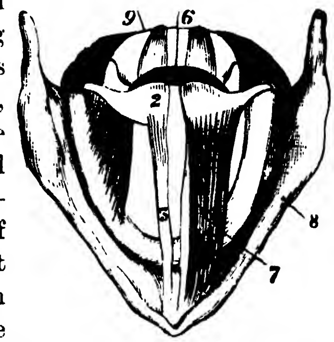


Fig. 4.—Diagrammatic View from above of Dissected Larynx.

This approximation is chiefly effected by the posterior arytenoid muscles (Fig. 4, *6*) which run from one cartilage (*2*) to that of the other side. Coming next to the question how the cords (*3*) may be made more slack or more tense, it is obvious that all that is necessary is to depress or elevate the arytenoid or the thyroid (*8*) cartilages so as to approximate or more widely separate the two ends of attachment of the vocal cords. The lowering of the thyroid would make the cords more tense, and this is chiefly effected by a muscle which, passing from the upper edge of the thyroid downwards and inwards, is attached to the cricoid cartilage (*9*), and is consequently known as the *crico-thyroid* muscle; this, by its contraction, depresses the thyroid, and so draws away the thyroid ends of the vocal cords from their arytenoid or inner ends. Similarly, a muscle passing upwards from the thyroid to the arytenoid —the thyro-arytenoid muscle (*7*)—draws the thyroid up again, and so, by making the distance between the ends of the cords less, makes them more slack.

We turn now to the question, why and how do voices differ? This is a question of pure physics, and it is necessary to remind the reader of what the conditions are, and what are the differences in the characters of sounds.

First, there is the *pitch*, which is the physiological expression for the length of the waves of sounds. This depends on different causes, according as we are dealing with rods, with open pipes, or with closed pipes. So far as we certainly know, it would seem that in the case of the human voice the pitch depends on the vibration of the true vocal cords, which vibrate more slowly the longer they are, and vary in vibration with the state of tension in which they are. Further, the column of air in

the windpipe has a proper rate of vibration, and it would seem that, by the influence of certain muscles, this tube is shortened or lengthened to bring its vibrations into harmony with the wave-lengths of the vibrations caused by the movements of the vocal cords.

Now, knowing that the longer the cord is, the more slowly it vibrates, we can see at once how it is that a deeper note, or one in which there are a smaller number of vibrations per second, is got from the vocal cords of an adult man than from those of a boy or of a woman, where the "Adam's apple" is not so prominent. One of the deepest notes sounded by a bass voice is produced by no more than eighty double vibrations in a second; while a soprano voice can, at any rate, give forth a note in which there are nine hundred and ninety-two such vibrations.

As it is obvious that a vocal cord can only be lengthened or shortened within certain limits, we can understand how a bass cannot sing soprano notes, or a soprano bass notes; and we get to recognise that each voice has a *range* or *compass* within which it is capable of producing certain notes.

Within this range a singer can sing with more or less *accuracy;* that is, of course, has more or less of command over the muscles which move the different cartilages of the larynx. What command practised vocalists can obtain over their muscles may be illustrated by the case of the singer quoted by Dr. Carpenter:—"It is said that the celebrated Madame Mara was able to sound one hundred different intervals between each tone. The compass of her voice being, at least, three octaves, or twenty-one tones, the total number of intervals was 2,100, all comprised within an extreme variation of one-eighth of an inch; so that it might be said that she was able to determine the contractions of her vocal muscles to nearly the seventeen-thousandth of an inch."

Delicacy such as this must, we cannot but think, be in part due to the sense of hearing—Madame Mara had a "good ear"—just as certainly as a man born deaf will never learn to speak of himself.

The false voice, or "falsetto," is still without a complete explanation. All we seem to know certainly is that during its production the vocal cords are wide apart, instead of forming a narrow chink, and we can hardly suppose that the vibrations then produced can gain any resonance from the column of air in the windpipes. As it is a matter of practice, it would follow that, like the ordinary or chest voice, it is ultimately due to certain contractions of the muscles of the larynx.

In addition to the larynx, or voice-organ proper, the mouth and the lips aid, as we all know, very greatly in the formation of those sounds which, when combined, go to make up *articulate* speech. The easiest sounds to make are the vowel sounds, and these we will now proceed to discuss. When we give off a vocal sound (according to Helmholtz, B flat), have the lips wide open, and the tongue lying flat, the sound is that of *a;* now, if we close the lips a little, alter the vocal note, and raise the back of the tongue, we get *e;* again raising the tongue and narrowing the lips more, the sound we make by the vocal cord has the characters of *i.* Let now the vocal note be F, the lips rounded, and the back of the tongue only a little raised, and we hear *u;* open the mouth a little, raise the back of the tongue a little more, sound the note B flat, and you pronounce *o.*

Having thus shown the method, it will not be necessary to deal in detail with all the consonants; as we know, in pronouncing *b* we shut the lips, in *t* we knock the tongue against the teeth, and when we say *g* we raise the back of the tongue. These three consonants are examples respectively of *labial, dental,* and *guttural* sounds. But when we sound *v* or *s*, we likewise give a labial or a dental sound, only instead of forcing air out, we seem to draw air in; while, then, *b* or *t* is an *explosive, v* or *s* is an *aspirate* sound. Yet again, if we take equal trouble to sound *f* and *v*, we find one much more distinctly audible than the other; or, to put it differently, we may say that *f* seems whispered—whispering being ordinarily defined as being speech without voice, though it would more accurately be defined as speech without vibration of the vocal cords, the lips in this case taking on the function of producing the sound-waves.

When we make a comparative survey of the animals allied to man's own class, we find that the parts which, in him, are the organs of articulate speech are most of them to be found represented. The frog has the lungs, the air-pipe, the glottis. That section of the vertebrata which is occupied by the birds exhibits the most remarkable diversity and complication of the vocal organs; they, like man, have a special chamber set apart for the heart and lungs, but they have not, as most mammals resemble man in having, *lips.* As has been well said, "As we trace these organs upwards, we invariably observe that, in proportion as the animals rise in the scale, a nearer and nearer approach is

made to the organisation of man. Indications, at length, gradually appear of an organ adapted for articulate language. But in no animal, not even in those most approximate to him, is the structure properly suited to be an instrument of speech. It is reserved to man to have that organ in its perfect condition." (A. Shaw.) Where things are *named*, the organ of speech reacts on the organ of mind, and a series of mental phenomena come into action, which are wanting in speechless animals. Further into this difference between man and brute we cannot here go; a full discussion would lead into not too easy philosophical disquisitions.

But there remains yet another difference, or another aspect of the difference :—"Short as is the reach of that 'pulse of articulated air,' and rapidly as its undulations disappear," yet can man, as Canon Farrar reminds us, "grave the symbols of its vibrations on the rock, or paint them on the vellum, or print them in the book, so that they can live from generation to generation, and reach from pole to pole."

A curious loss of power of language, known technically as *aphasia*, gives rise at times to ludicrous, and at others to painful accidents. True aphasia would seem to consist in this: that when a certain portion of the brain is affected, the patient may understand what is said, form ideas in correspondence, move his laryngeal cartilages, and yet remain speechless; the fact being, to all appearance, that in the injured part there lies a special centre, the activity of which is necessary for us to be able to convert *ideas* into words. Other forms of speechlessness are to be associated with an accident to the nerves which move the muscles, to loss of memory, or, at times, to such concentration of the brain-power that it is impossible for the brain also to act in the way of memory. We all know how, in moments of excitement or of earnestness, we cannot remember a word we want; it is "on the tip of our tongue," but our brain-force is altogether employed in other directions: we suffer a temporary aphasia.

Turning from man to the birds, we find at once a remarkable difference in the fact that in them the organ of voice is placed at the lower, and not at the upper end of the windpipe, and again in the complete absence of the vocal cords. Found at the base of the trachea, or at the point where this single tube is continuous with the two bronchi, we find that the *syrinx* may be altogether in the trachea, or altogether in the bronchus, or, thirdly, and as is most frequently the case, is bronchio-tracheal. In this last there is a *tympanic* chamber formed by the union of some of the lower rings of the trachea; a septum of membrane, which separates the tracheal orifices of the two bronchi; and thirdly, another membrane which is formed in the uppermost bronchial rings (Fig. 5). The mucous membrane lining these rings forms a fold which bounds one side of the cleft thus formed. These membranes are set in motion by the passing air, and the note formed depends on the position of the rings and the length of the column of air in the trachea; and that position is, as we may easily imagine, altered by the action of the connected muscles, the complicated arrangement of which was first distinctly made out for the passerines, or singing birds *par excellence*, by the illustrious German naturalist, Johannes Müller.

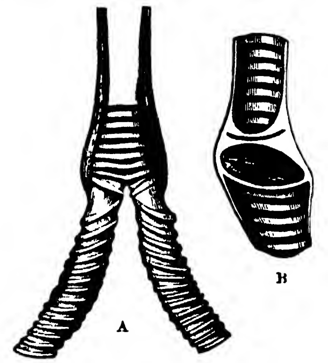


Fig. 5.—Larynx of Peregrine Falcon.
A, Front view; B, Section.

We refer to one group of insects—the order which contains the grasshoppers and crickets—for the purpose of figuring one of the most curious sound-producing organs which are to be found among them. Fig. 6, A, shows the inner portion of the right wing of an insect of this order (*Macrolyristes imperator*), and in it we may see that, while the hinder border is thickened to act as a cord (*s*), it has a tense membrane connected with it, and formed out of another part of the wing (*m*). Fig. 6, B, shows the lower surface of the part of the left wing which is nearest the body, and this may be

Fig. 6.—The Sound-producing Organs of *Macrolyristes imperator*, an Insect belonging to the Order *Orthoptera*.
A, Upper View of Right Wing; *s*, Cord; *m*, Membrane; B, Lower View of Left Wing; *b*, Roughened Edge.

seen to be roughened like a file (*b*) along one line; this file rubs on the thick cord, and sets the membrane in vibration. These organs are ordinarily, though not always, found developed only in the male; but, interesting though they are, it is unnecessary to enter into any further account of them, as the whole subject has been fully treated by Mr. Darwin.*

CRAG AND TAIL.

By J. Duns, D.D., F.R.S.E.,

Professor of Natural Science, New College, Edinburgh.

BRITISH systematic geology is the youngest of the great branches of natural science. It is not yet a hundred years old. Two works mark its beginning:—William Smith's "Tabular View of Strata" (1790), and Dr. Hutton's "Theory of the Earth" (1795). The latter was communicated to the Royal Society of Edinburgh in the spring of 1785. It was printed in "The Transactions" in 1788, and published separately seven years later. Special reference is made here to Hutton's great work, because of its influence on Sir James Hall, a contemporary young geologist, to whom we are indebted for the title of this paper, and for the first scientific statement and exposition of the phenomena to which it points.

Visitors to Edinburgh by rail may observe, as they near the city, a number of trap hills with bold, bare, precipitous fronts to the west, and gently-sloping ridges to the east. The term "crag" is applied to the western face, and the term "tail" to the long, gentle slope sheltered behind it. These features are not limited to the district now referred to; they occur over wide areas in Britain. Scotland is especially rich in illustrative instances. How are they to be explained? Can we get back to the dawn when they began to be? "Speak to the earth and it shall teach thee." Let us, then, take the facts of surface geology as words, and see if by piecing them together we can find the explanation of crag and tail. They demand careful attention on their own account. They have, also, a close bearing on our present subject. Our first reference takes us up the track of time to a far-off prehistoric past.

Nearly parallel to the central or Mont Blanc granitic ridge of the Alps, at a distance of about fifty miles, lies the limestone range of the Jura. The intervening space, consisting of hills and valleys, includes the deep depression in which Geneva and its lake are situated. Over the surface of this wide area innumerable blocks of granite are met with, some of great size and weight. They occur in the Jura at a height of 2,000 feet. Now, by what agent and at what time were the granites of the Alps carried to the limestones of the Jura? The questions bring in view some of the most interesting but difficult problems in the literature of surface geology. It is, moreover, all but certain, that we are to find the explanation of crag and tail in the action of forces the same as those which transported the granite boulders from their natural position to the places in which they now lie. We may pass at once from the question of time, because geological data are the expression of forces variable both in duration and intensity. They cannot therefore give a definite, or even an approximately trustworthy, chronology.

De Saussure, in his "Travels in the Alps" (1803), was the first who gave great prominence to the facts now referred to. He traced the occurrence of the granite blocks so far away from the central ridge of the Alps to the agency of diluvian torrents which, he thought, had swept with almost inconceivable force over the range of which Mont Blanc is the highest peak, carrying the granite masses with them. Hutton and his friend and interpreter, Playfair, attributed their presence to the ordinary action of rivers, at a time when the tract between the Alps and the Jura stood at a higher level than now. Professor de Luc, of Göttingen, rejecting the theory both of De Saussure and of Hutton, sought to account for the facts by a theory of ejectment. The blocks, he alleged, had been ejected by volcanic agency from the earth at the spots where they occur. Sir James Hall was of opinion, that, at an indefinitely remote period, when glaciers loaded with huge stones riven from the underlying rocks covered the Alpine heights, an immense diluvian wave, or series of waves, swept over the glacier area, carrying the ice with its embedded boulders in the direction of movement, and ultimately

* "Descent of Man," Vol. II., chap. x.

depositing the stones on their present sites. Oscillations of the surface are implied in the views of De Saussure, Hutton, and Hall. Later geologists seek the explanation in glacier action alone. We have thus five theories—1. Diluvian torrents (De Saussure); 2. River action, with altered conditions of surface (Hutton); 3. Local ejectment (De Luc); 4. Diluvian torrents and floating ice (Hall); 5. Glacier action (Recent Geologists). It would take us too far from our subject to criticise these in detail; but a few words require to be said as to the last. In 1840 Agassiz published his "Studies on the [Swiss] Glaciers"—a work containing an admirable *resumé* of the literature of the subject up to date, and accompanied by an atlas of thirty-two plates, representing the chief features of glaciation. James D. Forbes* formulated definitely for the first time the facts of glacier movement, and deduced therefrom its true law. Later, Robert Brown showed in a treatise on "The Physics of Arctic Ice,"† and in "The Physical Structure of Greenland,"‡ that most of the characteristics of the glacial remains of Scotland may be seen at present in the glacial system of Greenland, and that, oscillations of the land being assumed, the glacial phenomena of the two countries may be collated with at least some approach to accuracy. It might, indeed, be shown in detail that there are difficulties still to be removed. At present, however, we have to do with features of the surface which can be described by themselves, as is the case with crag and tail, though they find their only satisfactory explanation in the facts of glacier formation, movement, and influence.

Before the glaciers left our country they impressed their marks on its face. Let us look at some of these. They go a long way to help us to realise how crag and tail came to be. We can, for instance, remember once enjoying, after a long walk, a grateful rest on a huge boulder of grey granite, poised on the edge of an upland slope, among the slate hills of North Wales. The stone must have travelled far, and gently also, before it reached its present position.§ Again, at least 37 per cent. of the pebbles in the boulder clay around Liverpool are fragments of the rocks of the Lake District, fifty to seventy miles to the north. Some time ago a block of close-grained grey granite, between four and five tons weight, was struck in the course of draining operations, about fourteen miles to the west of Edinburgh. It must have travelled from the range of the Grampians, far away to the north-west. The "standing-stone" of Glenballoch, Perthshire, consists of mica schist, twelve feet high, and estimated to weigh twenty-five tons at least. It occurs in a red-sandstone district, and must also have come from the far north. Perhaps, too, this mass of mica schist may have a tale to tell of deeper interest to the geologist than that which the archæologist is trying to ascribe to it. The boulder is one of a series which marks the action of a prodigious force passing from north to south—a force not only equal to smooth the surface of the hardest rocks and leave deep striæ on them, but to produce all the features of crag and tail. These blocks of mica schist occur in Perthshire, in the Lothians, and in Berwickshire. There is one at Leith, another at Dalkeith, a third in the Pentlands, and a fourth on Cockburn Law, an outlier of the Lammermoor Hills. The position of these travelled stones is, in some cases, on the very edge of cliffs, where it would baffle man's skill to place them now. They are not, however, always far-travelled; they are often, like those associated with existing glaciers, fragments of the characteristic rocks of the localities where they are found. Here is an instance:—In the course of making a short line of railway for mineral traffic, about thirteen miles to the west of Edinburgh, the navvies came on an immense heap of stones, one of which was estimated to weigh above thirty tons, and all belonging to the rocks in the neighbourhood. The workmen had struck the moraine of an ancient glacier. The evidences of former movement were all around. Almost every stone had its edges rubbed off. The largest was polished as smooth as if it had been under the hands of the lapidary, and it in turn had polished the surface of the mountain limestones over which it had been dragged, showing clean sections of the shells of *Productidæ* and *Spiriferidæ*, with here and there pretty bits of Cup-corals (*Cyathophyllidæ*). Thus characteristic fossils of the coal measures, that had lived in a tropical or sub-tropical climate countless ages ago, meet the glaciers of comparatively recent time! Now, one has only to follow the polished and striated path of these boulders to the crags under notice, and to see the striation and the polishing continued along their precipitous face, to be convinced, with all but absolute certainty, that crag and tail has been formed by the same agency.

* "Travels in the Alps" (1843), and "Occasional Papers" (1859).

† "Quarterly Journal of the Geological Society" (1871).

‡ "Arctic Papers of the Royal Geographical Society" (1875).

§ The general doctrines connected with the "glacial period" are given in "Science for All," Vol. I., pp. 33—40.

Take an illustrative instance :—The ridge on whose western extremity Edinburgh Castle stands (Fig. 1) consists mainly of two rocks of unequal hardness, and therefore of unequal power to withstand all sorts of abrading or disintegrating influences. The volcanic rock on which the Castle is built is basaltic clinkstone of a greyish-black colour. To the west it presents a bold and almost perpendicular front; to the east a deep series of stratified rocks, red-sandstones and clay shales, with a thick bed of *till*, abut on the trap, presenting a fine section to the road on the south side of the Castle. The ridge is an elevated centre, which gives rise to two valleys —one on the north, in which the Waverley Station stands; the other on the south, in which the Grassmarket and Cowgate are situated. The valleys meet near Holyrood Palace, where they form one, whose outlet is the sea. The evidences of the action of several forces appear in connection with this ridge. The stratified rocks, in the form of a tail, lie at an angle of 12° to the volcanic crag, showing that they had been lifted by it from their horizontal position, and that the crag is more recent than they. At the time of upheaval the stratified rocks would surround the extruded trap equally on all sides. Now, however, they are exposed on the east alone. An abrading force, acting from the west, has carried away the soft strata, but the crag having power to resist it, turned one part of it to the north and the other to the south, scooping out valleys, while presenting a protecting front to the stratified rocks lying immediately behind it in the east—in a word, producing the phenomena of crag and tail. Features corresponding to these may be seen, on a small scale, on any sandy shore—Tenby, for example, where wide areas of sand are never covered by the tide. If a strong breeze blow continuously from one direction for a few days, any large stone or other steady object placed on the surface will be found bare to windward; while a tail of sand has, under its shelter, accumulated behind, tapering in proportion to the distance from the shelter. Sir James Hall sought for illustrations in the appearances presented in the bed of a river after a flood. Comparative stagnation of the water, he showed, takes place behind large blocks, which act as obstacles to the current, and there a deposit of transported matter is formed, "constituting a tail or prolongation which extends in the direction of the stream." But neither of the illustrations is

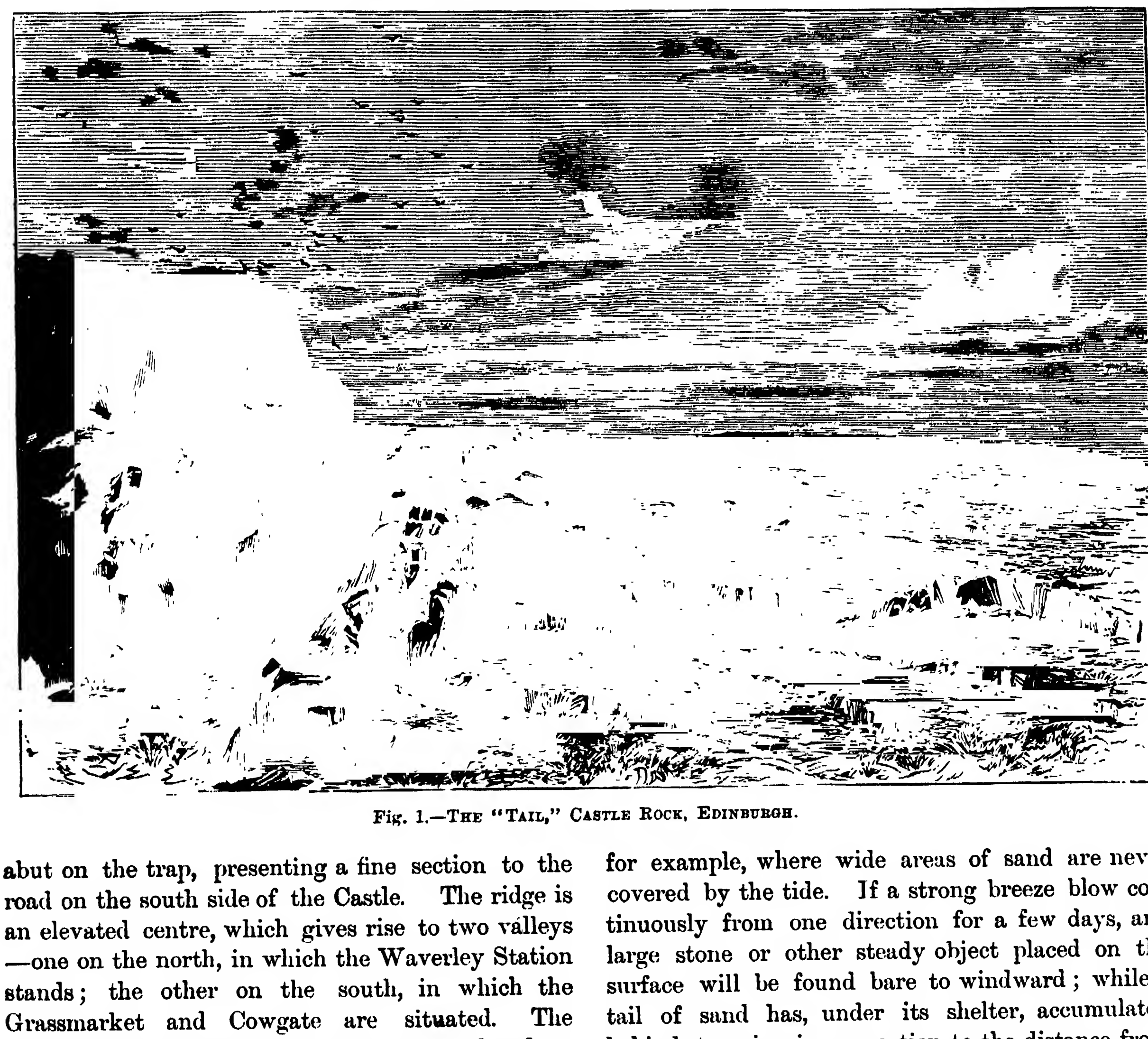


Fig. 1.—The "Tail," Castle Rock, Edinburgh.

wholly apposite, because we have not now to do with the deposit of the material forming the tail. What we wish to know, is the nature of the mechanical force by whose action crag and tail has been shaped from materials already in position.

Looking, then, at numerous instances of crag and tail that have come under our notice, we conclude that a denuding force coming from the west swept away the soft materials in its course till it met the crag of trap or other compact, hard rock, when it bifurcated, carrying with it the strata on the north and south, and leaving them on the east, that is, on the lee-side, only, in the form of a tail. The subject we have tried to describe is full of interest to all true students of nature. In it, and in its field surroundings, he will find full scope for his highest powers of observation and inference. And he will also find how many difficulties may bar the way to an exhaustive scientific explanation of phenomena perhaps long held to be patent and plain.

THE GENESIS OF A SWORD.

By C. Cooper King, Lieut.-Colonel R.M.A., F.G.S., Royal Military College, Sandhurst.

In the earliest ages of mankind, whenever those times were, two great necessities must have always been present in the daily life of the primeval peoples: first, that of obtaining food; secondly, that of defence against savage animals or human foes. When or how the sentiment of personal antagonism between individuals first arose it would be impossible even to conjecture; but that, after a time, members of the same or neighbouring families, who may have united for the common good or for purposes of mutual assistance, would display differences of opinion and jealousies, resulting finally in an appeal to physical strength, is certain, from what is known of human history through all time.

The strongest man with his native weapons—his fists—was unconsciously the father of all arms and all armed strength; for his weaker antagonist would early seek to restore the balance of power between them by the use of some sort of weapon. The shorter-armed man lengthened his striking power by the use of a stick, and found, after a time, the help its leverage and weight afforded him. The first case in which the chance-selected heavy-ended staff or club showed that weight and hardness had their value, was a step towards furnishing it with a stone head. Hence the blow of the fist was the forerunner of the crushing weapon. In the same way the pointed stick became the lance or dagger; and the thrown shaft, helped, as knowledge increased, by the bow or the "throwing-stick," was the precursor of the dart and arrow. The first weapons, therefore, were crushing, stabbing, and missile, and were probably carried by each fighting-man for the different circumstances of combat. From them have, almost insensibly, ramified the endless variety of forms that modern weapons show; and the successive steps of development have been, broadly speaking, the same with all races. In early days, it is open to question how far man was the originator of new ideas and forms. Such power of origination is the result of more skilled brains than the early savages possessed. At most they were copyists, and copied the details of the great page of nature's book that was ever open around them. Animals and insects furnished them with ideas and lessons; and, with this gradual mental training, arose the power of improving for their own purposes the types of the weapons the animals they slew possessed. They furnished man, as he became more skilful, with materials for weapons, as well as suggestions as to their form. Their bones, teeth, and tusks were in themselves, as he well knew by experience, formidable for attack and for defence.

So that, first of all, one may expect to find weapons whose very shapes were derived from natural types; and, next, that in the very earliest days materials were very limited. Wood first, then stone, and lastly bone and stone, for periods the duration of which is so long as to be beyond the range of guess-work, were the materials ready for Man's use. The animals he knew of crushed or pierced their prey, and he partly evolved from that fact his earliest forms of weapons. Hence arises the general similarity in character and shape of the earliest tools from all parts of the world. Similar materials, similar wants, similar sources of instruction, produced similar results.

The Tartar bow is precisely like that of the ancient Scythian; the axe and sword of the African Fans are identical in character with bronze celts and daggers from the Irish peat; the Zulu

assegai in shape and grooving of blade differs little from the head of the Saxon lance: like causes produced like effects.

Now the weapons of animals, as General Fox-Pitt-Rivers has so clearly pointed out, are piercing, striking, serrated, poisoned, or missile; and weapons made directly from those of some animals were used for similar purposes. Spears and lances are found made from the weapons of the walrus, boar, gnu, rhinoceros, sword-fish, narwhal, and antelope

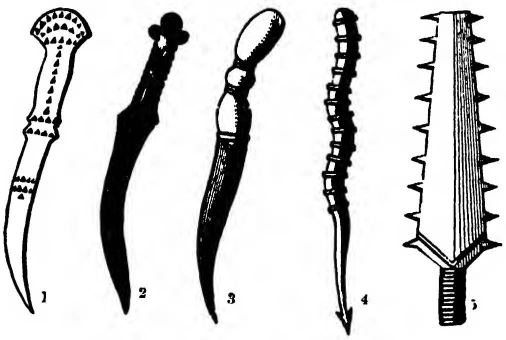


Fig. I.—Stabbing and Cutting Weapons, derived from Animal Forms.

(Fig. I., 4), to be used for piercing, as the animals themselves used them. The serrated bone of the sting-ray furnished both the material and example for many a South-Sea-Island spear. The saw-fish snout has given the natives of New Guinea a ready-made weapon (5), and the setting of the shark's teeth in the jaw has suggested their employment in making deadly the edge of a Tahiti sword (Fig. V., 5). The curved buffalo-horn and the wavy antelope-horn gave the types of the Indian kandjar (Fig. I., 3) and many other Eastern weapons. The hollow poison-fang of the venomous serpent not only gave a lesson to the South American Indians, who use a hollow poison-tipped spear, but indirectly suggested holes for poison in the poisoned arrow-heads, and grooves for the same purpose in the mediæval stiletto. The barbed insect sting, which held stoutly in its place after it had penetrated, fashioned, more or less, the first barbed arrow-head; and, lastly, the breaking off of the sting in the hostile body indicated to the Bushman how to make his weapon produce a like effect by half-cutting it through close to the head, so that it might break off and remain in the wound.

In the more temperate regions of the West, and in some other parts too, most probably, Man drew his early lessons from a still more simple source. The stones around him furnished his crushing, and, at first, very poor stabbing or piercing, tools. Long ages probably elapsed before he learnt that certain kinds of stone, notoriously flint or siliceous rocks, could be so roughly fashioned as to have a real cutting edge. The first club tipped with a natural stone must very soon have become the roughly-piercing, roughly-chipped axe. The production of the first sharp-edged flake must, thanks to its cutting power, soon have led to the fashioning of the tough and workable bones of animals slain in the chase or found dead.

So that nature, either through the medium of the animal world, or through its trees and stones, must have first given early Man ideas. The "living soul" that was in even his primitive race made him a facile, ready pupil, capable of gradually increasing development, who soon learned to go far beyond his mistress in the deadliness of his warlike tools.

Hence, to find the very beginning of the sword's history we must go back to an Age of Stone. This has two great divisions. The earliest, or "Palæolithic" age, when stone was merely chipped, is sub-divided into—first, that of the Drift-gravel people, who were hunting nomads, dwellers apparently by the sea or river-side; and secondly, that of the Cave people, who, being rather more civilised, occupied caves and rock-shelters on the escarpments of many a valley. At most, these latter were hunters. Both races lived when mammoth and woolly rhinoceros, hyæna and cave-bear, great aurochs, elk, and reindeer roamed through the vast dense forests of Northern Europe and Asia. Designed for crushing and piercing, though doing both badly, their weapons are simple enough; axe, spear, lance or dart, and arrow (Fig. II., 1, 2). None of them are sword-like yet, but one carved reindeer horn has become the stabbing dagger (4). Still the stone lance-heads (3) of the Cave-folk are getting longer, and are being chipped along both sides. There is the intent to get from the intractable material a longer cutting edge.

In the next great division of time, that of the "Neolithic" age, when mankind had learnt to delicately chip and polish their tools and weapons, the idea has become a little more developed. All the weapons cut better, all the lance-heads are thinner, sharper, and finer; and the dagger of stone, though its cutting power be weak, is dangerous in a strong hand. Generally the hilt and blade are formed from the same block of flint. Occasionally it seems as if the blade were intended to be fastened to a wooden handle by means of thongs or lashings, as the blades of bronze daggers

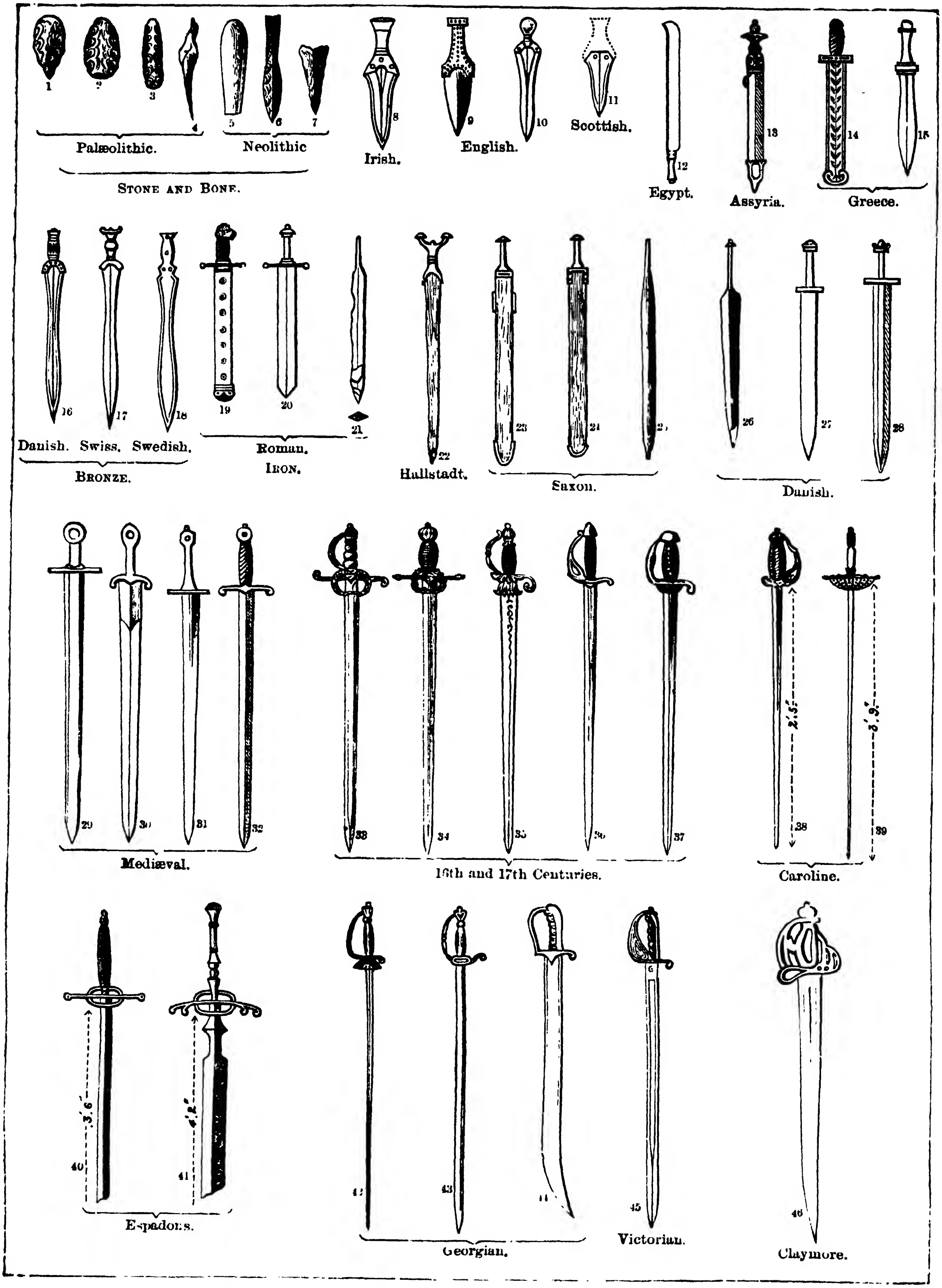


Fig. II.—STONE, BRONZE, AND IRON DAGGERS AND SWORDS.

were later on attached to their handles by rivets (6 and 7). Certainly the dagger has developed the form from which all other hand-weapons have slowly but surely come.

We see it again improved and lengthened in the next age, that of Bronze, when skill had so far increased that a compound metal could be smelted and moulded into shape, and taste and art lent their aid to its embellishment. Bronze man had much improved his dagger, for it is thinner, broader, more pointed, and more dangerous. Its leaf-shaped form in some cases, and its wide oval in others, point out that the remembrance of stone tools still survived in the artist's mind. Like the flint-daggers, they are not very long in the blade, and have often enough only a total length of about 10 inches. The handles of wood (Fig. II., 9), of ivory (10), or bronze (8), are often richly decorated, and are often peculiarly small. This may either imply an Eastern origin for the original type, since the hands of Asiatics are as a rule long, thin, and sinewy, rather than stout; or they may have been so designed in order to increase the firmness of the grip. For stabbing, no play to the wrist is required, and neither bronze sword nor dagger could do much else. Having no guards to the handle, they were not capable of being used for defence.

As time went on, the bronze dagger grew longer, and became a sword; still at first broad and leaf-shaped, but later on straight and pointed. Though externally it resembled the sword, it was, after all, only a longer-reaching dagger, some 20 to 30 inches in the blade (16, 17, 18). Its cutting power was small. It was no better than the axe, if as good. Sometimes the handle was solid, and had been cast with the blade; in other cases it was thinned out; and hence was, probably, plated with wood.

All historic nations seem to have passed through an Age of Bronze. The Assyrian sword was of this metal, broad, two-edged, and without a guard (13). The Greeks of the "Heroic Age" were similarly provided (14, 15). In the *Iliad* we read of Menelaus, that—

> "Around his shoulders slung, his sword he bore,
> Brass-headed, silver studded."

The term "brass" has often been used for bronze. Jewish swords are so designated, and were not large. Though the staff of Goliath's spear was "like a weaver's beam," his sword could be wielded by David's hand. Pausanias, Homer, and Lucretius speak of brass weapons. The Egyptians were also a bronze-using people, and probably had some method, such as the introduction of phosphorus, of hardening the alloy (12).

Here it is that the sword's real history begins. The true sword cuts as well as stabs, and that can only be perfectly done when the weapon is of steel. But as bronze became less commonly used, and iron took its place, the iron sword at first copied the shape of its bronze ancestor, and to some extent its nature too; for the first iron swords were still bad cutting weapons, and were only longer and more formidable stabbing ones than those of bronze. Generally they were broad, two-edged, and pointed. The Greeks seem to have used some such weapon in historic time. The blade terminated at one end in the narrowed tang, over which the bronze or wooden handle fitted, as sword-handles fit now. The swords found at Hallstadt (22) resemble those described by Polybius as used by the Greeks, and which were large, blunt, and soft, so that sometimes they "bent like a strigil" in cutting, and had to be straightened with the foot. Those from the Swiss lakes are no better. Tacitus says that the British swords were pointless, and were intended for cutting only; but this is doubtful. The Frankish iron sword was a powerful weapon, often 32 inches long in the blade, which was two-edged and sharp-pointed. With it was generally carried the dagger, or *scramasax*, which was often grooved to hold poison. Such swords were not in common use in early days, and in some cases were not highly esteemed. The *francisca*, the heavy Gaulish axe, was, after the *angon*, or barbed spear, had been thrown, probably more formidable than the soft sword, which had not yet become the emblem of power and authority. The spear, a walking-staff and at the same time a defensive weapon, was such with the Teutonic tribes.

Certain it is that the first swords after the Bronze Age were badly made and rudely tempered. They were true iron, not steel, swords, a little longer and very little better than the more elegant swords of bronze. It was the Roman who first produced the powerful weapon combining the virtues of the cutting and cleaving axe with those of the stabbing spear and dagger. It was the Roman *gladius*, sharp, of highly-tempered steel, and strongly piercing, that was the first real sword (19—21). Considering how common they must once have been, it is extraordinary how few undoubted specimens have been met with. Some five only are known—one found at Bischofsheim (21), near Mayence, was $1\frac{3}{4}$ inches wide and 25 inches long (over all), and had the point perfect and

almost quadrilateral in section. It was a powerful stabbing weapon, and was worn on the right side.

The Saxon sword (23, 24, 25), as may be expected, was evidently well-tempered and well-made. It was not even then an ordinary weapon, and was rarely worn by a man under the rank of Thane. At Brighthampton, those found were $35\frac{1}{4}$ to $37\frac{3}{4}$ inches long, and $2\frac{1}{2}$ inches wide; but sixty graves only produced four swords. The Saxon had become peaceful, and every man was not a warrior. Many a skeleton, unlike the custom of the Frankish, or even earlier nations, had merely a small knife by its side. At Fairford, in Gloucestershire, one was discovered with portions of the metal ornaments of the scabbard still adhering to it. It was $31\frac{1}{2}$ inches long in the blade, with a handle of $4\frac{1}{2}$ inches (24). As a rule, they were straight cut-and-thrust blades, with a double edge and a broad point. One found at Osnagel, in the Isle of Thanet, had a broad back and one edge, like a modern sword; but this is rare (25). Found, with horse-trappings, in the burial-mounds of Saxon chieftains, they were long weapons, suitable for mounted men.

From this period forward the character of the sword among the Western nations varied with the nature of the defensive armour that was adopted. At first they were simply developments of the broad iron blade of the early days, the blades being flat or somewhat convex in the centre, and occasionally made stronger by a central rib or ridge. As armour became stouter, so the sword was strengthened or stiffened, and at the same time lightened, by grooves or canelures. A mere cutting weapon was of no use against mail or plate. The sword had to do the work of the axe with its edge, and yet be still available for a thrust.

There are three methods of using the sword-edge. First, *slicing*, with wrist and elbow stiff, when the cut is given by the muscles of the back and shoulder. This is suitable to the sharp curved swords of Eastern nations, the action being that of drawing and cutting. Secondly, *chopping*, with shoulder and fore-arm, when the wrist has a little play, and the edge is not drawn across the object struck. This obtains among Western nations even now. Thirdly, *whipping*, with the wrist only, as in the case of the German "Schläger."

Of these, the second would be of most value against body-armour; and the mediæval swords, therefore, are stout, straight, and wide (29—32). Fencing, moreover—that is, the defensive use of the weapon to guard and parry, as well as to be employed offensively—seems to have been little regarded. The hilts are plain and simple, and there is no attempt made to protect the hands, clad as they were in mail. The sword had only become a good thrusting and cutting weapon, but not yet a good guarding one. That from the river Witham, in Lincolnshire (29), with its motto on both sides, and those from Denmark (26, 27, 28), are evidently strong enough to be used against armour; and the one found near the site of a Preceptory of the Knights of St. John of Jerusalem, at Sutton's Hone (30), in Kent, is of the same character. There was not much alteration, apparently, thought necessary in early mediæval days. The sword ascribed to Guy, Earl of Warwick (31), is only a longer, better-made weapon, but still shows no indication of real improvement. The age was one of brute force, and the swords are mere brutal, heavy, chopping weapons. In their plain cross-hilt (32), which varied little in form from the Norman Conquest to the fifteenth century, is the only evidence of a higher feeling. The oath of the knight, sworn upon the cross of his sword, was held sacred, because of the religious emblem it represented.

Armour varied in its character from time to time, but only to become stronger and heavier, until the introduction of fire-arms caused its partial, and finally complete, disuse. Thus, while mail-armour (which disappeared about A.D. 1300), mixed mail and plate (about 1410), and plate-armour (about 1600) lasted, the character of the sword varied little, save in fanciful alterations in length of blade, and shape and decoration of the hilt. In Southern Europe, about the fourteenth century, the blade first became narrower and more pointed, and the hilts were so constructed as to begin to guard the hand. Still, the change was slow; and it was not until Gustavus Adolphus did away with limb-armour altogether that the alteration of the sword into either the single-edged weapon, or else the rapier-blade, became general and common.

During all these early times the sword was treasured and highly prized. Joan of Arc took her battle-sword from a knight's tomb in the Church of S. Catherine de Fierbois; and the custom of consecrating the arms and armour of the newly made knight led to his sword being thought worthy of a place within the holy precincts of the sanctuary. In Saxon times, again, they were rare enough to be the subject of special bequeathment. Æthelstan, the son of Æthelred II., mentions in his will "the sword of King Offa, the sword which

Ulfeytel owned, and that with the silver hilt which Wulfric made." In Japan, until recent times, the well-tried sword was handed down from father to son as a precious heirloom. Many European swords carried texts or inscriptions on their blades, such as I.N.R.I., "In te Domine;" and in other cases the name of the place where they were made, as Solingen, Sahagun, &c.; and in others the maker's stamp or name, as Andrea Ferrara. In romances and troubadours' tales, too, they bore especial names. Charlemagne's Fusberta Joyosa; Arthegal's Chrysaor; St. George's Ascalon; Agricor's Tranchera; Rogero's Balisarda; Orlando's Durindana; and King Arthur's Caliburn or Excalibur, Mordure, and Margalay are instances of the quaint and fanciful titles applied to the trusty weapon.

The prices paid for them were high, considering the value of money in those days. In the reign of Henry IV. a two-handed sword cost 10s., and a single-handed sword, 6s. 8d.

The sixteenth century produced many varieties both of blade and hilt, and the revival of art led to an excess of decoration. With the disuse of gauntlets, in the time of James I., the plain cross-hilt became more or less basket-shaped, so as to enclose and protect the hand (33—37). Still, the swords were on the whole essentially trenchant. Many of the two-handed swords, or "espadons," such as those from Rochester and Canterbury (40, 41), were probably merely state weapons, to be carried in processions or at high ceremonies; though they were the national weapons of the Swiss in the time of Charles the Bold. Even the wavy, flamboyant blades that distinguished some of these swords, as well as those more easily wielded, may be ascribed either to grotesque fancy or the idea that the form of the edge influenced its cutting power. It is not likely that any religious sentiment caused this peculiar shaping, as may have been the case among Eastern nations.

But the chief and most remarkable change is the growing tendency to produce either a one-edged weapon or a merely pointed one. In both cases the blades of the many forms that distinguish the sixteenth and seventeenth centuries are marked by grooves, or canelures, that were rare among the flat or ribbed swords used against armoured men. The heavy cleaving type of sword ceased to be necessary. Grooves serve two offices: that of lightening the actual weight of the blade, and of, at the same time, stiffening it without interfering with its elasticity. It must be remembered that all cutting tools have an edge set at certain angles for certain work. Thus a knife-blade, which cuts soft materials, has the two sides set at an angle of from 10° to 20°; the chisel, to cut materials a little harder, such as wood, is best set with an edge of 25° to 35°; while to cut bone or metal, an angle of 40° is most suitable. But a blade with a complete triangular section, having its leading or cutting angle at 40°, would, if wide, be very thick at the back, and needlessly heavy. Hence, while the majority of swords have an edge of a similar angle, different methods have been taken to first diminish the thickness of the back, and then stiffen it by grooves.

The sections of different one-edged blades, though of great variety, are typified in Fig. V. (8—11).

The newer form of the hilt, when it enclosed the hand, limited the power of cutting to one side of the sword, while the simple cross-hilt admitted of either edge being used indifferently. Grooving, therefore, followed naturally on the alteration in the character of the weapon. Thus the still somewhat broad blades of Mediæval times often show several grooves, of which Fig. V. (17—21) gives examples. In the first two illustrations they are correctly placed to stiffen the sword, but have a tendency to weaken it; the third is better, as less metal is removed; the fourth is the old "regulation" type, and is a bad form; while the claymore section—the 5th—is again well-considered (United Service Institution Papers).

The claymore may be looked on as transitional between the trenchant weapon of the Middle Ages and the single-edged one of later times. But its heavy basket-hilt cramped the hand, and rendered it bad for parrying, as the early iron swords were, though from a different cause. But as with them the protection came from the mailed glove and the armoured dress, so with the Scottish claymore the target was used to ward off the hostile blows. The reason for its being two-edged it is difficult to account for, except as a survival of the ancient forms. The most noted sword-maker in Scottish history, Andrea Ferrara, lived and worked in the early part of the sixteenth century, when the traditions of his predecessors in the armourer's craft had not yet died out. His blades are needlessly heavy and powerful, except where armour had to be encountered; and their retention to so late a date as the eighteenth century may be attributed rather to the isolation of the nation, and the tendency to hand down the weapons as treasured heirlooms from father to son, than to

any special merit in their form or character (Fig. II., 46).

But the total abolition of armour, and the fashion of wearing swords as the distinction of a gentleman, produced a great and corresponding change in the nature of the fighting tool. Fencing, as an art, was capable of rendering a much slighter weapon deadly to use, and more elegant and graceful to carry. So that, for all purposes, except in the actual field of battle and the cavalry charge, the purely thrusting rapier took first place. It was better for personal conflict between individuals. While to deliver a cut the arm and weapon passed through the arc of the circle, to deliver the point involved the passage along its chord. With a quick eye and steady wrist, therefore, the rapier was better than the broadsword. Its appearance was not sudden, however. In the sixteenth century rapiers with flat or very slightly triangular blades, often immoderate in length, were used in France, Spain, and Italy. But the seventeenth and eighteenth centuries witnessed its full development (39 and 42). The blades are, as a rule, very narrow; the hilts have merely a single narrow guard for the back of the hand, and a broad base to protect the fingers in thrusting.

Here, again, the normal rhomboidal, or flat triangular, section of a straight thrusting weapon is altered, lightened, and stiffened by grooving. If the blade were merely flat and thin, as in the fencing-foil, it would be too flexible, and too liable to break. The sections have been modified, therefore, as in Fig. V. (12—16). The first is the so-called Saxon type; which, lightened, becomes the second example; and still further grooved, as in the third, the Toledo blade (Fig. II., 39); while, where the original form was triangular, it became changed to the Biscay pattern. The fourth case shows the French duelling-sword; and the ordinary Georgian walking-rapier is shown in the fifth illustration (U. S. I. Papers). But the form and character of the civil weapon influenced its military prototype. The fighting swords of the late eighteenth and early nineteenth centuries show the weapon with the rapier hilt; but with a rather wider, flat, single-edged blade, still having the power of cutting, but more useful as a thrusting sword (Fig. II., 43). The German factories of Solingen furnished many such; but the wide, shallow groove that lightened them weakened them for cutting. Worn similarly to the rapier, and used as a sabre, they had the true advantages of neither. They mark a period of transition to one almost of decadence. During the long years of peace that followed the Napoleonic wars, the sword as a civilian weapon had ceased to exist, and as a military one had few opportunities of development. Too much stress had been laid, even before that time, on the weight of the soldier's sword. Cavalry swords of the early part of the present century, and of the yeomanry and mounted volunteers of that time. are clumsy and unscientific. With great width of blade, and a tendency to increase the width towards the point (Fig. II., 44), they were not improved as cutting weapons, and were almost useless as thrusting ones. The evident idea that weight at the sword-end was valuable in enhancing the force of the cut is faulty in theory and practice. It was a retrogression to the principle of the axe rather than an advance in the true method of construction of the sword.

But contact with Eastern nations, whose swords were essentially cutting tools, led to a better appreciation of the form which the newer circumstances of

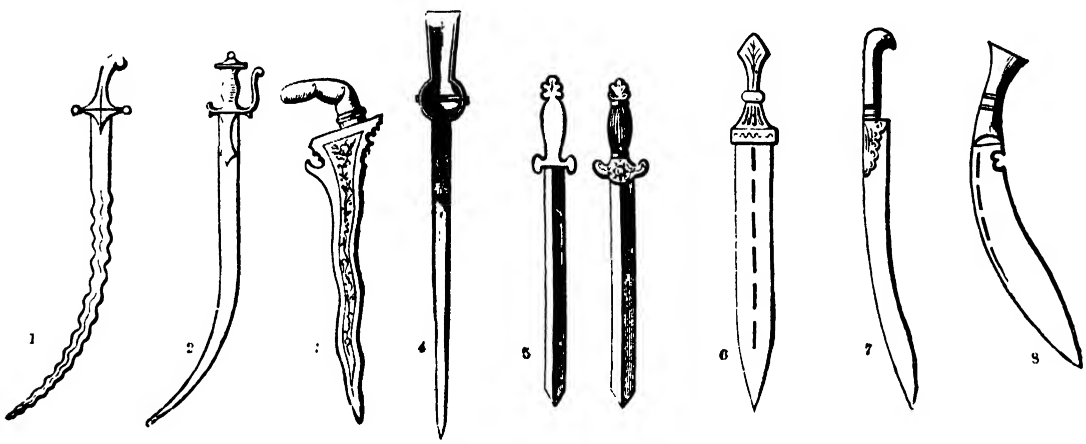


Fig. III.—Asiatic Types of Swords, Straight, In-curved, and Out-curved.

warfare had rendered necessary. The modern sword is so rarely used that it may as well combine within itself all the powers of which the weapon is capable. It must guard, be good for thrusting, and be useful for cutting. And a good modern sword fulfils these conditions. Slightly curved, but not so much so as to impede its pointing power, not so wide as to be too heavy, stiffened by grooves to be capable of use as a rapier, its blade, with an edge on one side along its length, is flattened at the point, where it is ribbed for strength, into a two-edged sword (45). Its hilt has a wider guard, and is intermediate between the rapier type and that of the basket form.

Adopting the principles that have obtained at various times, it is a good all-round weapon in skilful hands.

But while the Western nations, with heavy armour and great personal strength, have been led to adopt throughout their history a more or less straight blade, the Eastern races have, almost without exception, preferred the curved sword (Fig. III.). Sinewy rather than strong, quick and dexterous rather than determined, they have made cutting, instead of pointing or chopping, their system of swordsmanship. They seem to have moulded their swords to their system, rather than allowed their swords, as in the case of the rapier, to alter their method of fighting. Guarded by light and flexible, and therefore not easily crushed, armour, so different from the ponderous mail and plate of Europe, they trusted rather to the cut of the sharp curved edge than the downright blow of a straight edge. The Turkish scimitar, the Persian and Central-Asian swords, and the Indian tulwar are extensively curved. There seems to be no reason to apply a religious origin to this form, though it is common and almost special with Mohammedan nations.

For mere slicing purposes, the line of the hilt should be at an angle with the line of prolongation of the blade. It causes the edge to fall forward, or, as it is called, makes "the edge lead forward well." Thus the curved edge cuts like an acute wedge, and as if it were much broader and thinner than it is. It gives an enormous increase in real cutting power. Such work requires a firm grip and a steady wrist, the cut being given by the whole force of the muscles of the back and shoulder. Hence it is that the hilts of many Eastern swords are small, and that the boss, or pommel, at the end of the hilt is large, so as to prevent the sword from slipping when the drawing cut is made (Fig. IV., 2). Similarly, in other cases, the backward curve of the pommel of the Turkish yataghan is so formed as to resist the effort of the drawing cut to pull the weapon from the hand (4). Smallness of hilt is not necessarily chosen, because Easterns are naturally small-handed, but possibly to ensure a firmer grip.

Then, again, there is much greater divergence of type in Asiatic swords; and, though some may be due to accident or fancy, others are based on religious feeling. The wavy blade, resembling the conventional tongue of fire (and technically called "flamboyant" in the West), may well be due to the influence of the priests of fire or of the sun. Thus the Persian scimitars (Fig. III., 1) are often wavy, as also are the Malay creeses (3). These latter, intended for stabbing only, have the cross of the hilt correspondingly large and strong, to aid in pressing the blow home. Doubtless, the waviness may be sometimes copied from the curvature and ornamentation of the antelope-horn dagger (Fig. I., 4), which has even in modern times served as a weapon. Similarly, the shape of the animal's horn, of which some daggers were made (Fig. I., 1), has repeated itself, firstly, entirely in metal (2), and, lastly, in metal with ivory hilt (3).

Other distinctions in form seem to be tribal and local rather than general. The Chinese swords, two of which are carried in the same sheath, are short, straight, two-edged, and pointed (Fig. III., 5). The Bashi-Bazouk or Circassian dagger (6) is straight, broad, two-edged, and sharp-pointed, resembling the Roman gladius in blade, and the archaic bronze

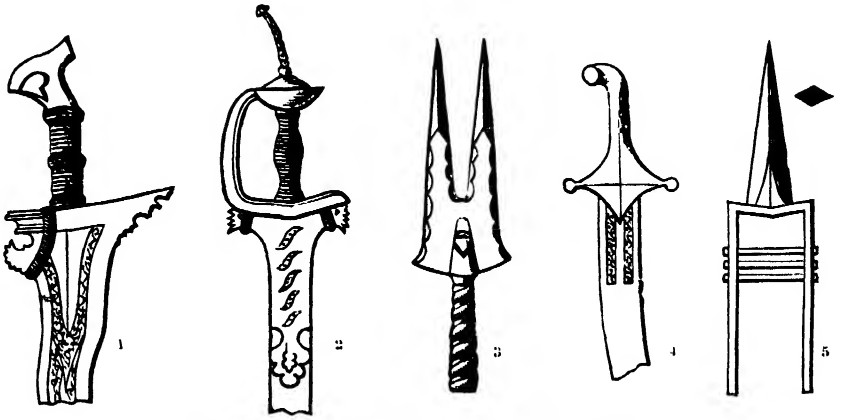


Fig. IV.—Survivals of Methods of Attachment, &c.

swords in hilt. Many of the Mahratta swords are quite straight; and some have the hilt formed like an iron gauntlet, in prolongation of the long blade, preventing wrist-action altogether (4). The Albanians and some others carry a sword rather longer than the last, but with the edge thrown forward by the slight forward curvature of the blade (7). This is carried further and increased in power in the Ghoorka knife, by making the fore part of the blade considerably wider and heavier (8). Both these and all similar forms seem to indicate that their object is to make the blow both a chopping and a drawing one. A well-trained Ghoorka can, it is said, decapitate an ox by one blow of his formidable "kookerie."

solid metal, the ancient method of attachment by a twisted cord, which now has no meaning. In the tulwar (2), again, the way in which the original blade with a broad top was lashed by cords to the hilt is clearly indicated. The Mahratta spear-head (3) points out, from the character of the lines on its iron socket—part of the bifid head itself—that the first pattern was lashed to the shaft by a cord. The tongue at the base of most Indian, Persian, and Turkish swords is the metal representation of the projection from the hilt of the sword, round which and the underlying blade the fastening was passed (4).

There is a further similarity to be traced in the probable rhomboidal point of the Roman gladius

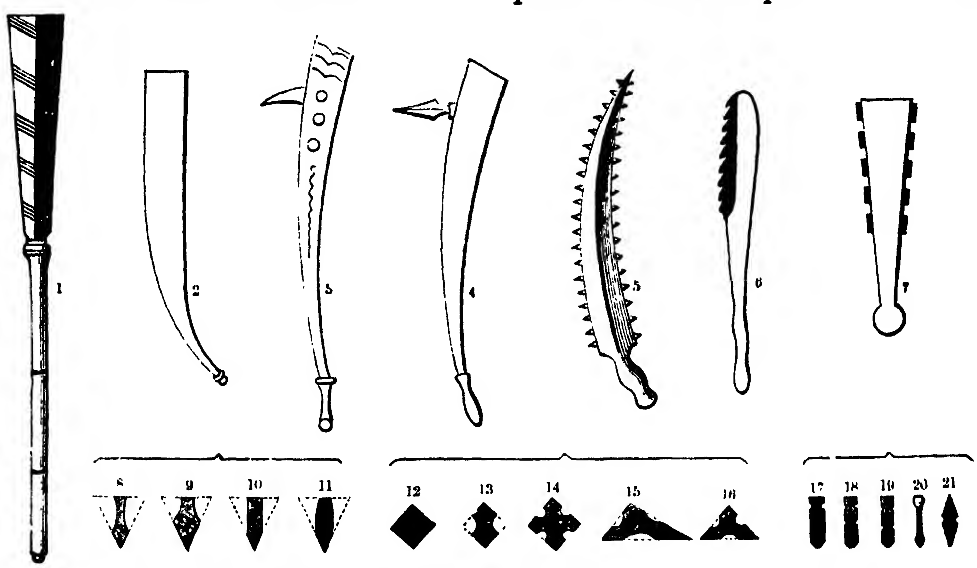


Fig. V.—Development of the Sword among Savages; and Sections of Sword-blades.

Evidently these curved forms lend themselves to a system of cutting or slicing sword-play, different entirely from the methods that have through all historic time characterised the use of the weapon in Europe. Either curved forward or backward, the effect of the cut is enormously enhanced. Thus the cutting section of the blade is much more formidable at the curve than on the straight; and, as all Eastern blades are kept exceedingly sharp, the mere form of the curve, if the hand be merely advanced or drawn back, facilitates, and in fact necessitates, a deep cut.

In all these weapons, European as well as Eastern, the ornamentation is very frequently but the survival of the methods by which blades were fixed to their hilts. As a rule, it must be remembered, the latter were made separately, and attached by thongs or rivets. Thus in the Malay creese (Fig. IV., 1) the hilt shows, carved in the

and that of the Mahratta dagger (5). Both were chiefly intended to give a deadly thrust. Certainly the Indian weapon with its stiff-wristed fore-arm hilt had no other *raison d'être*. Similarly the deep ornamentation and holes often found in daggers are not always evidence of the present use of poison, but indicate certainly its former use in similar weapons.

Among savage nations the sword does not rank so highly as the spear or club. It belongs to a higher civilisation than that which is satisfied with hand-to-hand weapons of wood and stone. But the development of the club into the sword is easily traceable, though the ultimate resultant is far inferior to the metal blades of even the Bronze Age. Fig. V. shows the successive steps. The New Zealand club (1); the Indian colleree stick (2), often used as a missile; the Iroquois club (3, 4), rendered good for piercing or cutting as well as

crushing by a deer-horn point at first, and by an iron blade later on, in times when metal was procurable; the Marquesas (5) or Tahiti cutting instrument, armed with sharks' teeth; the Eskimo and Australian sword (6), in which chips of meteoric iron, obsidian, or glass, are inserted in a cleft in the side of a stick, and fastened by cement; and, lastly, the Mexican Maquahuilt (7), or wooden sword, armed with sharp, razor-like flakes of obsidian, are the progressive steps of savage life towards the sword. The last-mentioned was deadly enough to be ranked with its iron compeer, for it is said to have been capable of cutting off a limb. In this respect it is the highest type of a sword made of other materials than metal.

Of all weapons, the sword has held throughout historic time the highest place. Its use implied the personal courage of the individual at close quarters. The arrow might slay at a distance, and be discharged by a coward. The spear, again, if long enough and deftly held, could kill without risk to the holder thereof, unless the adversary were similarly armed. But the sword meant personal conflict, where the victory was not always to the strong. Rightly it is the sign of might and of governance, for it implies both the will and power to execute the behests of its holder. It is one of the insignia of authority, because it is the sign of courage and of skill. The sword of justice symbolises the reign of order and law. The officer's sword is to-day the outward sign of his commission from the Queen. The flaming sword at the gate of the primeval Paradise represented the force of righteous power, and is a religious emblem too.

HOW TO MAKE A CHEMICAL ANALYSIS.

By Professor F. R. Eaton Lowe, M.A., Ph.D.

THE combustion of gases, the spontaneous ignition of solids in air and in water, the beautiful transitions of colour produced by precipitation, the transformation of solids into liquids, and liquids into solids, the detonation of fulminates, the explosion of mixed gases, the smoke-rings of phosphuretted hydrogen, the symmetrical forms of crystallisation, and the wondrous revelation of the spectroscope, are some of the phenomena which have attracted many of our most eminent chemists to the study of a science in which they have afterwards gained so much distinction.

The determination of the constituents of a compound substance, and of the proportions in which such constituents exist, are operations which tax his resources and ingenuity to the utmost, and constitute a crucial test of his knowledge, care, and manipulative skill.

The candidates who take the chemical paper at, say, the University Local Examinations, are expected to give practical proof of their knowledge of testing. For this purpose a number of substances, such as metallic oxides and salts, are presented for analysis. Some of these salts, the composition of which is, of course, unknown to the candidate beforehand, are simple, that is to say, consist of one "acid" and one "base" only, while others are mixtures of several acids and bases. A knowledge of *qualitative* analysis only is sufficient to pass the student in this paper. A substance is examined qualitatively when it is sought to ascertain the constituents which enter into its composition, without regard to their relative quantities; but when we wish to discover the weight or volume of such constituents, the analytical processes to be employed are of a different kind, and are termed *quantitative*. A quantitative analysis involves much greater manipulative difficulties, and requires to be conducted with much more care and exactitude than one which is simply qualitative; for the slightest loss or error in collecting, drying, or weighing the precipitates will sadly vitiate the results. Some expertness in what may be called mathematical chemistry is also essential. The law of chemical equivalents, for example, furnishes the student with the means of calculating the proportions of acid and base in any given salt without actually isolating and weighing them.

We proceed to explain a very easy method for the analysis of a simple salt, which can be learnt in a few days by an intelligent student, who need not necessarily possess anything but a mere smattering of the science to enable him to practise it with success. By this method the following "acids" and "bases" can be readily detected, provided that the salts to be analysed are pure and free from organic or other extraneous matter.

Bases.

Class I.—Potassium, Sodium, Ammonium.
„ II.—Barium, Strontium, Calcium.
„ III.—Manganese, Iron (protosalts), Magnesium, Cadmium, Bismuth.
„ IV.—Zinc, Tin (protosalts), Aluminium, Lead, Tin (persalts), Antimony.
„ V.—Mercury (protosalts).
„ VI.—Copper.
„ VII.—Nickel, Chromium, Iron (protosalts and persalts mixed).
„ VIII.—Mercury (persalts), Gold.
„ IX.—Iron (persalts), Silver.

Acids.

Class I.—Nitrates, Chlorates, Chlorides, Iodides, Arsenites, Sulphides.
„ II.—Fluorides, Phosphate, Arseniates, Borates, Oxalates.
„ III.—Carbonates.
„ IV.—Sulphates.
„ V.—Chromates.

Before commencing operations, we must have at hand the following reagents in solution :—Soda carbonate, ammonia, caustic potash, potassium ferricyanide (red-prussiate of potash), and sulphuretted hydrogen. To make these solutions properly, we must provide ourselves with some of the simpler pieces of apparatus already described.* The most essential of these are the following :—three or four flat-bottomed glass flasks, varying from four to ten ounces in capacity, a few beakers of similar capacity, some glass stirrers, a small porcelain mortar, some platinum foil and wire, a pipette, a dozen large test-tubes, test-tube holder, two small tubulated retorts, retort-stand, three or four feet of narrow glass tubing, glass funnel, filtering paper, red and blue litmus paper, and a spirit lamp, or Bunsen's burner. We are now in a position to prepare our reagents. We begin with the soda carbonate, of which we have to make a saturated solution to be preserved for testing purposes.

To make a saturated solution of any salt it is best to use boiling water, as more of the salt is likely to be taken up, although this is not always the case, for common salt (sodium chloride) dissolves equally well in hot and in cold water. We will then select a flask capable of holding five or six ounces, and nearly fill it with distilled water. An ample supply of this water must be always in readiness, as no other can be used for analytical purposes. Distilled water is usually prepared by means of the apparatus figured in Vol. IV., p. 196; but failing this, an ordinary retort fitting into a bottle by way of receiver can be employed (Fig. 1). The distilled water usually sold by the druggists is impure, having been made in copper retorts. If the water gives the slightest precipitate with barium chloride or silver nitrate, it must be rejected as containing salts of lime, or traces of sodium chloride. Having adjusted our flask upon the ring of the retort-stand, about two inches above the lamp, or Bunsen's burner, which is far preferable, we heat the water, and add in small portions at a time the carbonate of soda previously reduced to a fine powder in the mortar. The powder must not be taken up with the fingers, but may be dropped into the flask from a piece of glazed writing-paper. The water is saturated when no more of the powder is dissolved after repeated stirring. Allow the solution to cool, and pour into a stoppered bottle for use in subsequent operations. With regard to our second reagent—liquid ammonia—no preparation is necessary, as the saturated solution used in testing is kept in a sufficiently pure state by every chemist. The third reagent to be prepared is solution of caustic potash (potassium hydroxide). This is sold in the form of round sticks or irregular lumps, and the solution is made and saturated in the same way as our standard solution of soda carbonate.

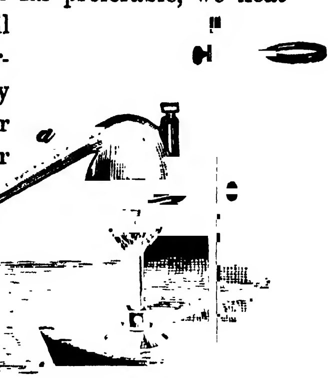


Fig. 1.—Simple Form of Apparatus for Distilling Water.
a, Long-necked Retort; *b*, Flask; *c*, Basin of Cold Water for Condensing Steam.

The solution of ferricyanide of potassium, or red prussiate of potash, is similarly prepared, but to make the solution of sulphuretted hydrogen, we shall have to fit up the necessary apparatus for producing the gas and conducting it into the water to be saturated. An arrangement for this purpose is represented in Vol. IV., p. 197, where three flasks are employed for generating, washing, and collecting gas. In the first bottle the gas is produced by the action of dilute sulphuric acid upon iron sulphide; in the second bottle it is washed, or purified, by being allowed to pass through a small quantity of water; and finally, in the third, it is absorbed by the water, which takes up many times its own volume of the gas.

This solution is a very valuable test for many of the metals, with which it produces sulphides of

* "A Chemical Laboratory:" "Science for All," Vol. IV., pp. 195—202.

characteristic colours. The stopper of the bottle in which it is kept must be replaced immediately after use, as the solution decomposes by the action of the air, and becomes discoloured.

We are now ready to begin our analysis; and a simple salt, in crystal or in powder (the latter is the usual form, as being less recognisable), being handed to us for examination, we proceed to divide it into four portions. One of these portions serves for the detection of the base, another for the acid, and the remaining two are reserved for confirmatory tests. Having made a solution of the salt as strong as the quantity at our disposal will permit, we pour a small portion into a wide test-tube, and add, drop by drop, solution of sodium carbonate. If we perceive no precipitate, especially after boiling, then we are to presume that there is present one of the metals in Class I. Which of them it is, we now proceed to determine. Take a little of the dry salt, and mix with it an equal quantity of dry sodium carbonate, together with a few drops of water. Heat the mixture in a test-tube or small evaporating dish, and if the well-known pungent odour of ammonia is produced, then we are certain that the unknown salt contains the base *ammonium;* but if not, we must proceed to discriminate between the remaining two metals—potassium and sodium. Take a little of the salt, and fix it in the loop of a platinum wire, and heat it in the blowpipe oxidising flame, as in Fig. 2. If a strong yellow colour is communicated to the flame, the metal present is *sodium;* but if there is no change of colour, or a slight tinge of violet is perceived, the metal must be *potassium.* If the smallest trace of soda is present in a salt of potassium, the yellow colour alone will be observable in the flame. It is, therefore, advisable to employ two additional confirming tests.

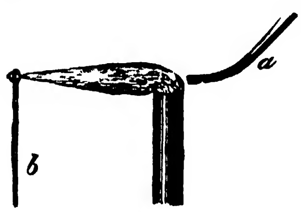


Fig. 2.—Exposing Bead to the Oxidising Flame.
a, Point of Blowpipe; *b*, Platinum Wire.

To a concentrated solution of the salt add a drop of bichloride of platinum. A yellow precipitate indicates potassium, while no precipitate indicates sodium. To another portion of the concentrated solution add a few drops of a strong solution of *antimoniate of potash.* No precipitate indicates potassium, and a white precipitate, slowly formed, indicates sodium.

We have thus shown how the metals in Class I., which are the bases of the alkalies, can be readily determined. If at the commencement of our operations we obtain a precipitate without carbonate of soda, we know that these three metals are excluded, and that we must look for the base amongst the remaining eight classes. In this case the precipitate gives no further indication, and we proceed to make a trial with the next reagent—liquid ammonia.

To a fresh portion of the solution we add the ammonia drop by drop. If we get no precipitate we are sure that there is present one of the metals in Class II.—barium, strontium, or calcium. To determine which of these our salt contains, we adopt the following means:—Add to the solution a few drops of *potassium bichromate,* and if a precipitate is obtained the metal is barium; but if there is no precipitate, take another portion of the concentrated solution, and add solution of yellow *chromate of potash,* or potassium chromate. If a precipitate is formed the metal is strontium, but if not it is calcium. We can here again have recourse to that useful instrument, the blowpipe, to confirm the above indications. Make a little bead with the dry salt at the end of a platinum-wire, moisten it with water, and heat in the reducing flame, as in Fig. 3. If a green colour is communicated to the flame, the metal present is barium.

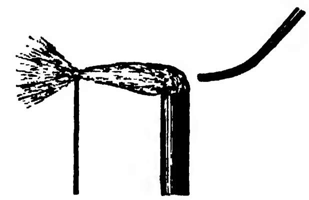


Fig. 3.—Exposing Bead to the Reducing Flame.

If the flame becomes red, the metal is either strontium or calcium. These may be distinguished from each other by solution of sulphate of lime, which gives a precipitate with strontium, but not with calcium.

We have thus disposed of Class II.; but if we succeed in getting a precipitate with the liquid ammonia, we must proceed to test a fresh portion with caustic potash. The solution must be dropped in by means of a pipette (Vol. IV., p. 200), as a slight excess of the reagent may dissolve the precipitate at first formed, or prevent its formation altogether (Fig. 4). If we obtain a white precipitate with the caustic potash, we proceed to ascertain

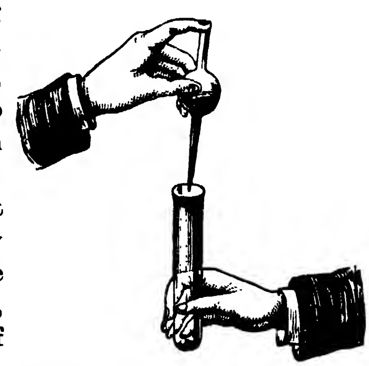


Fig. 4.—Testing with Caustic Potash.

whether the precipitate is soluble or insoluble in excess of the reagent.

This action of potash is important, as it furnishes us with the means of distinguishing the metals in group three from those in group four. If the precipitate is insoluble, the metal must be sought for amongst those in Class III., but if it dissolves or disappears, the metal is one of those in the next class.

The metals of the first of these groups are discriminated as follows: Add to the solution of the unknown salt some red prussiate of potash; if we get a brown precipitate the metal is *manganese;* if blue, it is a protosalt of iron; if there is no precipitate it is *magnesium.* The remaining two metals are distinguished from each other by sulphuretted hydrogen, which gives a yellow sulphide with *cadmium,* and a black one with *bismuth.* To confirm these results we again call in the aid of our blow-pipe. Make a borax bead on the platinum wire, which is easily done by making the wire red-hot in the flame and dipping it into some powdered borax. Melt a little of the dry salt which we are analysing into this bead, and heat it in the outer or oxidising flame; the bead will acquire an amethyst tint—in fact, this action of manganese gives us a clue to the manufacture of artificial amethysts. Again, mix a few grains of the dry salt with an equal quantity of dry carbonate of soda, and put the mixture into a little hole scooped out in a piece of hard charcoal. Direct the point of the blowpipe flame upon it for a few seconds, and we shall obtain a kind of green glass. When we come to iron we may use as a confirming test *potassium ferricyanide* (yellow prussiate of potash). This gives a white precipitate with protosalts of iron, which however rapidly turns blue, and a dark blue precipitate with persalts of iron.

If we find that the white precipitate obtained by caustic potash is re-dissolved by excess of that reagent, we proceed to test another portion of solution with *potassium ferricyanide.* A reddish-yellow precipitate indicates *zinc;* a white precipitate indicates a protosalt of *tin;* the remaining four metals can be easily discriminated by sulphuretted hydrogen, which gives no precipitate with *aluminium,* a black one with *lead,* a yellow one with a persalt of *tin,* and an orange one with *antimony.* Salts of lead are well adapted to illustrate the action of the blowpipe. If a little of the salt is mixed with carbonate of soda or microcosmic salt as a flux, and heated upon charcoal (Fig. 5) in the inner or reducing flame, the metal will, in a few seconds, be reduced; that is to say, its affinity for the acid with which it was associated will be overcome, and it will appear as a bright metallic globule on the

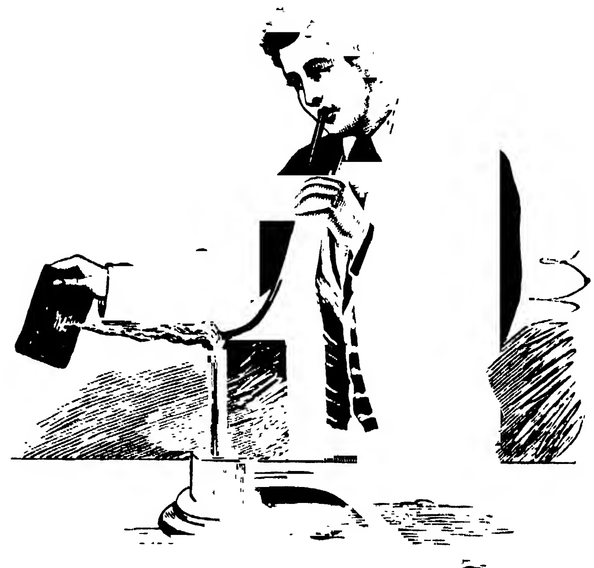


Fig. 5.—Assaying upon Charcoal.

charcoal. The experiment may be repeated with similar results with a salt of tin or copper; but if the base is volatile, as in the case of mercury, a combustion-tube must be used, when the metal will be sublimed, or appear as an incrustation upon the side of the tube. The inner blowpipe flame only is adapted for the purpose of reduction, because here, as in the interior flame of a candle, the combustion is imperfect, and the heated carbon seizes upon the oxygen of the salt and releases the metal. In the outer flame the reverse effect takes place: for here the air has free access to the flame, and being highly heated, is ready to part with its oxygen to any metal that may happen to be in the way. The experiment may be tried with a small fragment of lead, heated upon charcoal in the outer or oxidising flame. The temperature of this flame is sufficiently high to melt the lead, which does not liquefy below 600° F.; and it will soon become converted into a greyish powder, and subsequently, by the absorption of more oxygen, into a yellowish mass composed of brilliant scales. This is the well-known *litharge,* or lead monoxide (PbO) so much employed in the arts.

This litharge can readily be reduced, or reconverted into a bead of metallic lead, by heating in the inner flame. The student should try his powers with the blowpipe on salts of tin, bismuth and antimony.

The beads of these metals may be distinguished

from those of lead by not being malleable or convertible into yellow oxides. Beads of bismuth are brittle, and those of antimony when allowed to fall from the charcoal divide into a number of smaller globules, which emit a thick, white smoke of antimony oxide.

To return to our trial with caustic potash. If we get a black precipitate the substance will be a protosalt of *mercury;* and blackish precipitate is sometimes obtained from gold, but the two may be distinguished by trial with *potassium ferricyanide,* which gives no precipitate with the latter, but a reddish-brown one with mercury. If our potash gives a blue precipitate instead of a black one, the base is one of the two in Class VI.—cobalt or copper. There will be no difficulty in distinguishing these from each other. If the solutions containing the blue oxides are boiled, the one which contains *cobalt* will turn *red,* while that which contains *copper* will become *black.* A little of the dry salt of cobalt, about half the size of a pin's head, melted into a borax bead on the platinum wire, will give a beautiful dark-blue glass both in the outer and inner flames. Oxide of cobalt is thus used as a pigment for staining glass and porcelain. There are many confirming tests for copper, all of which are of an interesting character. The action of the blowpipe flame upon salts of copper is instructive. Melt some of the salt into the borax bead and heat in the outer flame: a transparent green glass will be obtained. Try the experiment in the inner flame, and the result will be an opaque brown glass. In the first of these cases an hydrated oxide of copper, or the oxide in union with water, is formed, while in the latter, the unconsumed carbon of the reducing flame, ever greedy of oxygen, causes the dehydration of the oxide, which then assumes its ordinary black colour. The salt may be reduced in the usual way upon charcoal (Fig. 5), when metallic copper will appear in the form of scales of the characteristic reddish-brown colour. A strong heat and a steady blast are required for this experiment, as copper will not melt below a temperature of 1900° Fahr., and the student who has not acquired the practice of using the blowpipe without frequently leaving off to take breath, and thereby interrupting the blast, will not succeed in reducing salts of copper. A striking confirming test for copper is found in the addition of liquid ammonia to a solution of the salt. A splendid blue colorisation is the result, and this will be produced even when the salt is present only in small quantity. The deep blue liquid of the druggist's show bottles is produced in this way, being the ammonio-sulphate of copper, or copper sulphate and ammonia. Another equally characteristic test is the decomposition of the salt by iron. Make a strong solution of copper sulphate or nitrate, and dip into it a piece of polished iron or steel, as the blade of a knife: a coating of bright metallic copper will be immediately formed upon its surface, because the acid has a stronger affinity for the iron than it has for the copper, so that, instead of sulphate or nitrate of copper, we have in solution sulphate or nitrate of iron. This fact can easily be verified by the *potassium ferricyanide* test already described. Now, instead of a white, black, or blue precipitate with potash, suppose we obtain a green one; our metal will then be one of Class VII.—nickel, chromium, or iron protosalts and persalts mixed.

Turning to our *potassium ferricyanide,* if we get a greenish yellow precipitate the metal is *nickel;* if no precipitate, it is *chromium;* and if a light blue, it is *iron.* A little ammonia added to a salt of nickel gives a violet-coloured solution. Chromium, like copper, is interesting from the use of its oxide as a pigment for glass, porcelain, and other substances which have to be exposed to a high temperature. Oxide of chromium is green, and its property of staining glass may be demonstrated on a small scale by the borax bead and platinum wire. Melt into the bead a very small piece of the dry salt, and heat either in the inner or outer flame. In either case we shall get a transparent green glass. In this way a copper salt may be distinguished in the dry state from a chromium salt. The metals in Class VIII. give a yellow precipitate with caustic potash, that from gold being sometimes blackish. The potassium ferricyanide will give a reddish yellow precipitate with *mercury,* but none with *gold.* There will, however, be no precipitate with mercury perchloride. This, however, may easily be distinguished by reduction in a glass tube with soda carbonate or potassium cyanide, which is often a better flux when metallic mercury in silvery globules will be sublimed, and may be caused to run together into a single globule. We now come to the last class, which contains the two bases—iron (persalts) and silver. These yield a brown precipitate with potash. To distinguish one from the other, we turn to our potassium ferricyanide, which gives no precipitate with *iron,* but a brown one with *silver* The behaviour of silver salts with hydrochloric acid must here be noticed. If hydrochloric acid or

solution of any chloride be added to a salt of silver, a white precipitate of silver chloride will be formed. This will be found to be soluble in ammonia, but insoluble in nitric acid. The dry salt may be reduced upon charcoal by the blowpipe, producing a bead of bright metallic silver. It has already been shown that salts of copper are decomposed by iron; soluble silver salts are in like manner decomposed by metallic copper. The experiment is an entertaining one, as under proper conditions the metal is deposited in an arborescent form, producing the well-known "silver tree." A good plan is to place a strong solution of silver nitrate in a wine-glass of such dimensions that it will support a copper coin about an inch or more from the bottom. The silver is deposited upon the under side of the coin, and ultimately hangs down like an inverted shrub.

We have thus discovered the base of the unknown salt, and the more difficult part of our task is completed.

The next business is the *Examination for the Acid.* For this purpose we must prepare standard solutions of the following four reagents—barium nitrate, silver nitrate, lead nitrate, and calcium chloride. Having made a concentrated solution of the salt to be analysed in the way already described, we test it with our first reagent. If we get no precipitate, the acid will be found in Class I.; that is to say, it will be either a nitrate, chlorate, chloride, iodide, arsenite, or sulphide. This being settled, we proceed to test another portion of solution with the nitrate of silver. If we get no precipitate, the salt is either a nitrate or a chlorate; if we obtain a white precipitate, it is a *chloride;* any other precipitate indicates one of the remaining three acids of the Class. We have now to discriminate between nitrates and chlorates. Put a little of the dry salt into a large test-tube, and add hydrochloric acid. Hold the tube over the lamp or burner, and if the salt is a *nitrate,* white fumes of nitric acid, which redden litmus paper, will be expelled. If the salt is a *chlorate,* a yellowish green gas, having a very pungent odour, will be given off. A nitrate heated in the dry state with dry bisulphate of potash gives off a dark yellow gas (nitrous acid). This effect is not produced with a chlorate. Both nitrates and chlorates give off oxygen when melted in a test-tube. A taper or match that has just been extinguished will be re-lighted if plunged into the tube. To distinguish between *iodides* and *arsenites* we must have recourse to the lead nitrate, which gives a yellow precipitate of iodide of lead with the former, and a white precipitate with the latter. *Sulphides* are readily tested by nitrate of silver, which yields a black precipitate of silver sulphide. A good confirming test for an iodide is bisulphate of potash. If some of this in the dry state is heated in a large test tube with an equal quantity of the salt under examination, decomposition will take place, and the characteristic violet vapour of iodine will be observed. To confirm for arsenites, mix a very small quantity of the dry salt with carbonate of soda, and heat upon charcoal in the inner blowpipe flame. After a short ignition the odour of garlic will be perceived, by which the presence of metallic arsenic in the state of vapour is rendered evident. It need hardly be said that the student had better not linger over the poisonous fumes of arsenic longer than is necessary to recognise the characteristic odour. Sulphides may be detected by the smell of sulphuretted hydrogen gas, which is given off when they are heated with hydrochloric acid. The dry salt and the acid are put into a test tube and slowly heated over a small flame. The odour of this gas is by no means so agreeable as that of arsenic vapour, being generally likened to that of rotten eggs, but it is equally unmistakable and characteristic. If we desire further confirmation as to its identity, we have only to allow the gas to impinge upon lead paper, or paper moistened with a solution of any lead salt, and the paper will turn black, owing to the production of lead sulphide. The acids in Class II. give a white precipitate with barium nitrate, which in each case is soluble in nitric acid without effervescence. If we get no precipitate with silver nitrate, the acid is a *fluoride;* if a yellow, it is a *phosphate;* and if a brown, it is an *arseniate.* The borates and oxalates are distinguished by calcium chloride, which, with the *borate,* gives a white precipitate which dissolves on adding more water, and with an *oxalate* a white precipitate insoluble in water. To confirm for fluorides mix some of the dry salt with bisulphate of potash in a test tube, and apply heat. Hydrofluoric acid gas, which has the property of corroding glass, will be disengaged, and if Brazil wood test-paper is exposed to its influence, its colour will be turned to yellow. The corrosion on the glass will be best observed after washing and drying the tube. The most delicate test for phosphoric acid is *Molybdate of Ammonia.* Add to a solution of this reagent as much nitric acid as will dissolve the precipitate it first produces, then add a very small quantity of the phosphate,

and boil in a test-tube: we shall obtain a yellow precipitate. No other acid than a phosphate will yield this precipitate with an acidified solution of molybdate of ammonia. The oxalates are interesting from the decomposition which they suffer when heated with sulphuric acid. The operation is performed in a test-tube over a moderate heat; effervescence takes place, and a gas is given off which is a mixture of carbonic oxide and carbonic di-oxide, or carbonic acid. On applying a light to the mouth of the tube the former burns with a blue flame, notwithstanding its dilution by the incombustible carbonic acid. From a soluble borate we can obtain boracic acid, which tinges the flame of alcohol of a beautiful green colour. To obtain the acid in crystals, boil a concentrated solution of a borate with sulphuric acid, and let the mixture cool. The boracic acid will appear at the bottom of the test-tube or evaporating dish, in which the operation may be conducted, in the form of flat shining crystals. These should be collected on a filter, and repeatedly washed with water to remove all traces of sulphuric acid, and kept for subsequent experiments. To observe the green flame, dissolve some of the crystals in alcohol or methylated spirit in a saucer, and inflame the mixture, stirring occasionally with a glass stirrer. Class III. contains only the carbonates, which also give a white precipitate with barium nitrate, but are distinguished from those in Class II. by dissolving in acids with effervescence owing to the escape of carbonic acid gas. The sulphate in Class IV. also gives a white precipitate with nitrate of barium, but it is quite insoluble in acids. We shall have no difficulty in distinguishing chromates, as they are the only salts on our list which give a yellow precipitate with barium nitrate. A sulphate may be further identified by the following process. Mix some of the sulphate with dry carbonate of soda, and heat on charcoal in the inner blowpipe flame. After a few seconds' ignition remove the fused mass and place it upon a piece of bright silver. After a short time a black mark will be observed on the metal, owing to the production of silver sulphide. If the substance presented for analysis prove to be insoluble, it must be examined by the blowpipe, both upon charcoal and in the borax bead. Its insolubility is ascertained by evaporating a little of the water in which we have attempted to dissolve it to dryness. There should be no residue. We have thus discovered both the base and the acid of the unknown salt, and our task is completed.

Experience has proved that the analytical course here presented to the reader, though necessarily brief, is sufficiently copious and explicit for all practical purposes, and that the young student, with the scheme before him, will be able, after a week's good practice, to analyse any simple salt, provided that it is pure, and does not contain any other acid or base than those which appear on our list. He must set about his work, however, in a methodical manner, as if he were competing with other candidates at a public examination, when ultimate results, even if correct, would not be accepted unless all the intermediate steps leading to those results are accurately noted. Pen, ink, and paper, then, are essential adjuncts to his apparatus. The colour and character of every precipitate, and with what reagent produced, must be jotted down in their appropriate columns; the metal or acid indicated by these precipitates, and the class to which it belongs, must then be prominently recorded, together with the blowpipe and other tests used to confirm the results already arrived at. The analysis of compound substances and mixtures composed of several salts is a much more complicated business, the practice of which the student would do well to defer till he has thoroughly mastered the scheme here presented to him.

A PIECE OF CHALK.

By Professor Charles Lapworth, LL.D., F.G.S., etc., Mason College, Birmingham.

THE small piece of white chalk, which, from its constant use in the school-room, the lecture-room, the billiard-room, and the workshop, may be regarded as a daily necessity of our modern civilisation, has, in spite of its simple appearance, a strange history, the unravelling of which through all its complexities is one of the most difficult problems with which the science of the present day is called upon to deal. This piece is, in reality, a chip of an immense block of chalk that once filled an area the size of the present continent of Europe, and of which even yet several gigantic fragments remain,

each larger than the collective area of a dozen average British counties. These patches occur scattered over the region lying between Ireland on the west, and China on the east, and extending in the other direction from Sweden in the north to Portugal in the south. In the British Isles the chalk is found in greatest perfection and continuity in the east and south-east of England. A sheet of chalk, more than a thousand feet in thickness, underlies all that portion of England which is situated to the south-east of a line crossing the island diagonally from the North Sea at Flamborough Head to the coast of the English Channel in Dorset. This enormous sheet of chalk is tilted up slightly upon the west, and its depressed eastern portions, that dip towards the waters of the North Sea, are usually buried from sight by masses of overlying sands and clays. But wherever these are pierced through by the well-sinker, the chalk is invariably met with below, as solid and compact as ever. The western edge of this great chalk floor has not been much disturbed, but its southern margin has been crushed upwards, so that the chalk now stands perpendicularly on edge in the cliffs of Dorset and the Isle of Wight. A little farther to the east also, in the Weald of Kent and Sussex, the chalk floor has been warped up into a rude arch which has been partially worn away by rain and rivers, and the underlying strata laid bare. The rocks upon which this great sheet of chalk reposes in the south-west of England are a series of sands and clays, which from their soft and incoherent nature, are rapidly worn away by the action of the weather. The chalk itself is much harder and tougher, and is consequently far more highly resistant of meteoric degradation. Hence it follows very naturally that these underlying beds, which form the basement of the country lying to the west of the long line of the outer edge of the chalk formation from Flamborough to Dorset, are all worn down by rain and rivers to a comparatively dead level; while the hard "basset edge" of the great chalk floor is comparatively unaffected, but stands out in a bold ridge, looking out upon them everywhere like the edge of a vast terrace or well-marked range of hills. In Yorkshire, Lincoln, and Norfolk, the hills forming the edge of the chalk floor are known as the Wolds. In the east of the Midland valley they compose the long inland ridge which terminates in the Chiltern Hills. Westwards the same basset edge looks out in the hills of White Horse, Marlborough and Dorset, while the corresponding ridges of the North and South Downs partially encircle the eroded arch of the Weald.

The scenery of these chalk heights is as a rule comparatively tame and monotonous, but it has frequently a picturesque character and prettiness all its own. The Wolds and Downs, on the outer edge of the chalk floor, compose an endless succession of soft and gently undulating heights; bare above, but partly clothed below with scattered patches of woodland. These rounded summits and the elevated plateaux lands which back them, are covered with a thin mantle of soil, overgrown by a short sweet grass, cropped by innumerable flocks of sheep. But where the edges of the chalk floor come upon the sea, the cliff scenery to which they give origin is strikingly grand and beautiful. He who has once seen the magnificent rocks of Flamborough and Beachy Head, the jagged stacks of the Needles or the dizzy mass of Shakspere's Clift near Dover, must have felt something of the majesty of the chalk headlands—the white cliffs of Albion.

The massive sheet of white chalk which underlies the whole of the south-west of England is deeply dug into by the waters of the Strait of Dover; but it again makes its appearance in France, forming much of the floor of that country for many miles beyond Paris. It is found also at numberless localities in Europe, as far east as the Crimea, and even in Central Asia beyond the Sea of Aral. Northward it occurs as far as Scania, in the south of Sweden. Southward, its limits seem to be near the centre of the Spanish tableland. How far it stretched westwards towards and into what is now the Atlantic we may never know; but chalk of a thickness of at least 200 feet is exposed in the beautiful cliffs of Antrim in Ireland; while less conspicuous relics of the formation are found in a few localities in the counties of Argyle and Aberdeen. There can be little question that all these now isolated patches were once connected in a continuous sheet, which must therefore have occupied a superficial area about 3,000 miles long, by nearly 1,000 miles broad, an extent larger than that of the present continent of Europe.

Chemically, chalk is a carbonate of lime. That is to say, it is composed of a mixture of lime with the gas called carbonic acid, so familiar to us as escaping into the air with great bubbling and fizzing when a soda-water bottle is opened. If a quantity of chalk be carefully powdered and flung into a large quantity of ordinary vinegar, a rapid effervescence is at once set up, the carbonic acid

gas escaping into the atmosphere, and the lime being dissolved by the vitriol, vanishing wholly from sight. Again, if a quantity of chalk be burnt, the carbonic acid is expelled by the heat, and a mass of white matter remains which is identical with the quick-lime of the mason, swelling in the same way when water is thrown upon it, with great evolution of heat, and finally falling down into a soft white powder. Thus, in spite of its peculiar appearance, its soft texture, and homogeneousness of structure, chalk is identical in character and composition with an ordinary limestone.

Now we know that the vast majority of limestones were formed in the waters of the sea, mainly from the accumulated débris of the coverings of the shell-fish that flourished upon the sea-floor; but, at first glance, it would appear that chalk must have had a very different mode of origin. It has been already pointed out in these pages* that a piece of limestone differs from a piece of chalk in several important particulars. When a slice of ordinary limestone is viewed under the microscope, it is found to be made up of the fragmentary slices of a multitude of organisms—shells, corals, sea-lilies, and the like—whose shattered fragments are all easily identified by the skilled zoologist. But when a transparent slice of chalk is examined in the same way, we find no trace of any of the creatures found in the limestone. The chalk seems to be formed of a multitude of little bodies of a most peculiar form (Fig. 1). Each of these minute bodies is very symmetrical in shape, and is clearly built up of a number of globular chambers, arranged in a series. The most common form has its chambers disposed in an elegantly spiral manner, and reminds us of the beautiful nautilus shell, occasionally seen in our museums. These objects are all scattered irregularly in a white granular dust, which fills up the spaces between them. Not only, then, does chalk differ from limestone in its structure, but when regarded in mass also, the two rocks are quite as strikingly contrasted. Limestones, as a rule, seem to have been mere calcareous fringes to ancient lands, rapidly changing in nearly all their features when followed for some distance. Chalk, on the other hand, as we have already intimated, occupies an area as large as that of the entire continent of Europe, and its lithological characters remain everywhere the same.

When we visit a typical chalk quarry for the first time, the contrast between the appearance of the rock which is being excavated, and that familiar to us in the many limestone quarries scattered over Britain, is somewhat startling. Instead of a solid mass of grey rock, clearly disposed in definite layers, we have before us a steep face of chalk, destitute of anything like lamination, but rising up like a solid white wall. Embedded in the chalk at different heights are a few horizontal layers of stone, which even from a distance we infer must be much harder than the chalk in which they are embedded, as they project in well-marked shelves or ledges. Here and there, too, we notice perpendicular ribs, pillars, or vertical projections of the same hard-looking rock, but less definite and continuous than the level shelves; while, in addition, a few knots of the same nature are seen scattered irregularly through the body of the chalk itself. If we pull down a piece of one of the horizontal layers of hard rock, and strike it with our hammer, the sudden flash which leaps forth shows us that it is, in reality, a mass of flint. Exteriorly, its surface is almost as white as that of the chalk itself; interiorly, it is hard, black and glassy. The upright pillars, and the scattered blocks are found to be also composed of the same material as the shelves. The upright pillars themselves—the "potstones" of the quarry-men—are pear-shaped masses of flint, usually having an internal cylindrical cavity filled with hardened chalk.

Fig. 1.—Microscopic Fossils in a Piece of Chalk.—1. Globigerina; 2. Nodosaria; 3. Rotalia; 4. Coccoliths; 5. Sponge-spicu es, &c.

Although these appearances add to the many differences which distinguish chalk from ordinary limestone, and appear at first glance to indicate a very different mode of origin, a more extended

* "Science for All," Vol. I., p. 14.

study of the chalk rocks soon convinces us that this hasty conclusion is erroneous. Fragments of sea-urchins, corals, lamp-shells, skeletons of cuttle-fishes, &c., and all the usual types of sea creatures may, by the exercise of care and patience, be collected out of the body of the chalk itself; while the clays and sands in which the chalk formation is embedded, are crowded with well-preserved fossils of sea animals, and are admitted by all to have been deposited in the waters of an open sea.

But, until within the last few years, the problems presented to geologists by this extraordinary chalk deposit seemed well-nigh impossible of solution. They had to reconcile the fact that chalk is almost identical in chemical composition with ordinary limestone, with the conflicting fact that it is of a totally distinct internal structure. They had, moreover, to explain the presence, meaning, and preponderance of the peculiar-chambered structures found in the chalk; and at the same time to show why the prevalent organic ingredients of ordinary limestone are invariably absent. They had, further, to make it clear why flint, so rare in ordinary limestone, is so abundant in the chalk formation; and why it occurs, not only in horizontal layers, but also in vertical pillars, in interlacing veins, and in isolated nodules. Finally, as every other rock formation has its apparent analogue now in course of accumulation under the waters somewhere upon the surface of the globe, they were bound to point out some special region, where —over an area as large as Europe—an aqueous formation resembling chalk was actually in process of deposition at the present time.

Now, it is one of the proudest achievements of modern science that it has at last partially solved this grand enigma—in a few brilliant strokes, reconciling these apparent contradictions, depriving the

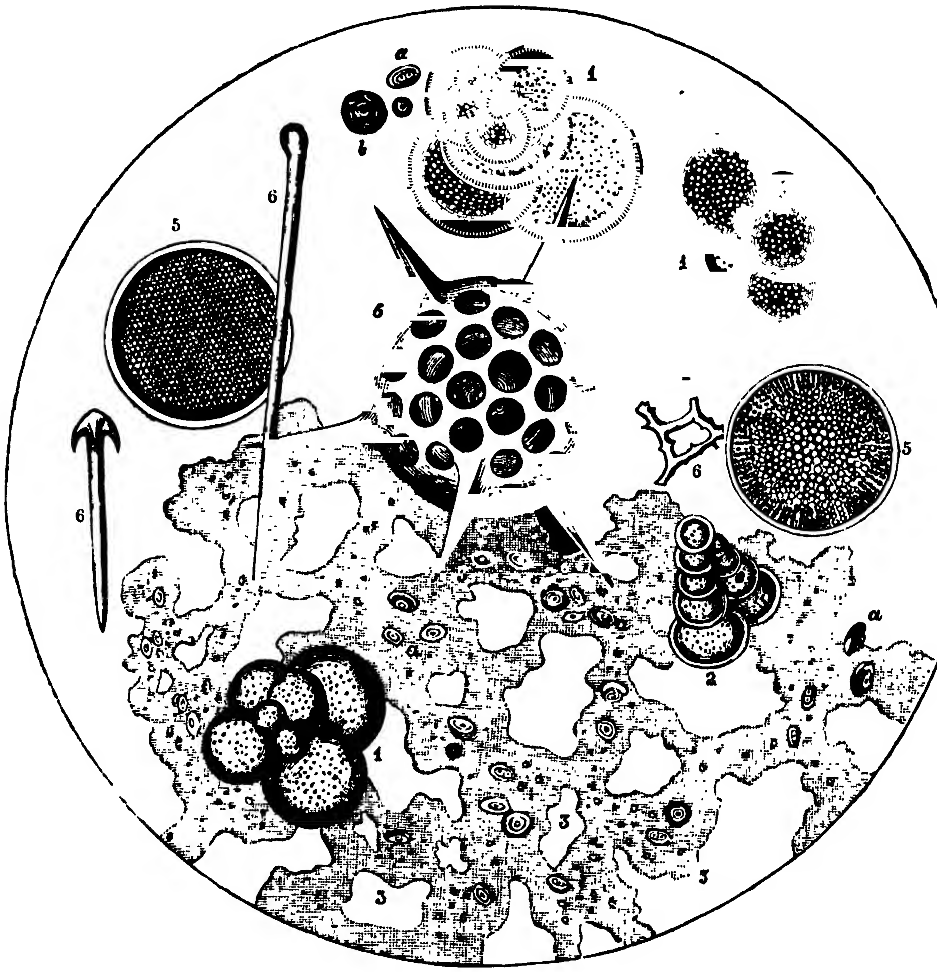


Fig. 2.—Shells, etc., in the Globigerina Ooze of the North Atlantic.
1. Globigerina; 2. Textularia; 3. the so-called Bathybius, with (a) Coccoliths and (b) Coccospheres; 4. Radiolarian; 5. Diatoms; 6. Sponge spicules. (*After Zittel.*)

strange chalk formation of nearly all its abnormalities, and placing it in its simple and natural position as one of the great geological formations.

Previous to the laying down of the first cable which united the Old World to the New, it was deemed advisable to make a preliminary survey of the ocean floor upon which the cable was to repose, extending between Ireland and Newfoundland. In the course of the survey samples of the mud lying upon the sea floor were dredged from the bottom, and submitted to Drs. Ehrenberg and Huxley for placed under a microscope, it was noticed at a glance that it was filled with the peculiar bodies so abundant in a slice of chalk (Fig. 2). Here, then, it was immediately acknowledged, a substance was being laid down upon the sea-bottom at the present day, which might eventually be consolidated into a rock identical with chalk; and laid down too, over an area as enormous as that covered by the chalk itself; and at the same time, like the chalk, preserving the same general characteristics everywhere within that area.

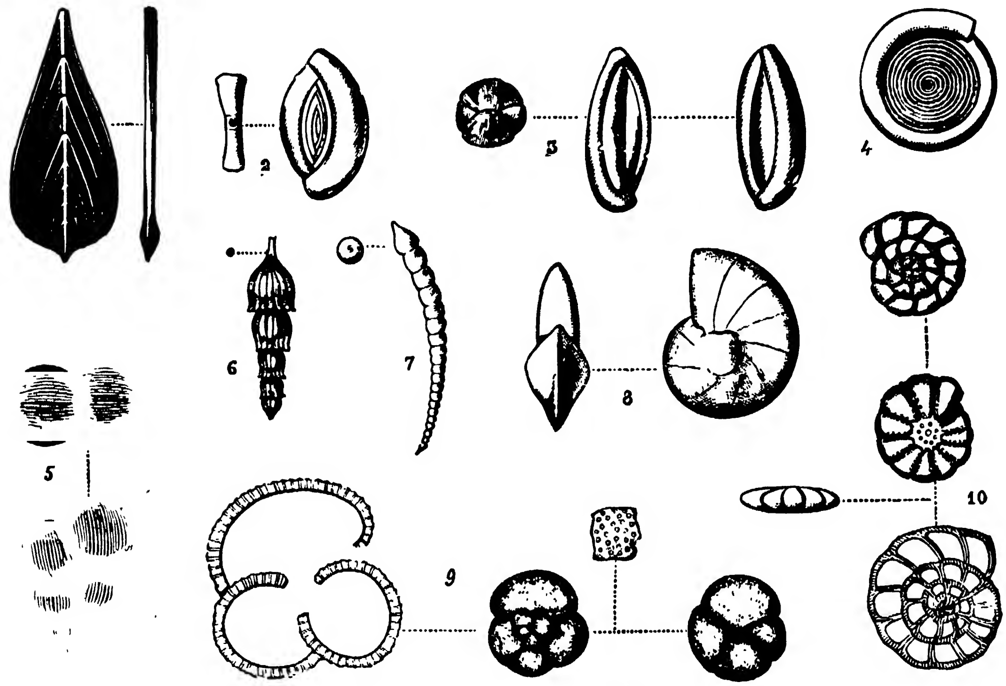


Fig. 3.—SHELLS OF FORAMINIFERA.
1. Frondicularia; 2. Spiroloculina; 3. Quinqueloculina; 4. Cornuspira; 5. Textularia; 6. Nodosaria; 7. Dentalina; 8. Cristellaria; 9. Globigerina; 10. Rotalia.

examination. This mud was found to be actually a whitish or greyish matter, not unlike thick cream in general appearance. It is known to the sailors as *ooze*—a word derived from the Anglo-Saxon term *wase*, mud, and familiar to most of us as the title of some of the more sluggish mud-bearing rivers of England. When dried it hardens into a soft mass not unlike chalk in outward appearance; while, like chalk again, it is composed almost entirely of carbonate of lime.*

Not only did the dried ooze resemble chalk in chemical composition and outward appearance, but there was another and most important respect in which the great investigators we have named found the ancient chalk and this modern deposit to be identical. When a small quantity of the ooze was

* See also "Science for All," Vol. III., pp. 80—1.

The long-sought-for key had apparently been discovered. The chalk formation ought henceforth to be regarded as a consolidated deep-sea ooze, which must have been laid down upon the floor of an ancient Atlantic that once overspread the western half of the Old World from Britain to the Hindoo Koosh.

The natural question follows, what are these microscopical bodies that make up the bulk of the chalk and ooze, and why do they abound in such extraordinary numbers? To the zoologist they are perfectly familiar. They are the shells of a species of the family of *Foraminifera*, a group of microsopic sea animals, all of which in the living state have much the appearance of specks of animated jelly; but which all possess the power of building up for themselves shells of remarkable structure and beauty.

These shells (Figs. 2, 3) usually consist of a series of hollow chambers united into a complex structure of exquisite symmetry. In some of these shells the chambers have a linear necklace-like arrangement; in others they alternate on opposite sides of a central line; in others again, they are set in irregularly overlapping rows; while in the genus *Globigerina*,* which is by far the commonest form, both in the modern ooze and the ancient chalk, the chambers are disposed in an elegantly expanding spiral. As a general rule, the outer wall of each of the chambers in the complex shells of this family is pierced with a multitude of minute openings, through which the jelly-like lodger inside thrusts forth a host of gelatinous fingers, which interlace themselves into a complex network devoted to the collection of the inconceivably minute particles of organic matter disseminated through the water in which the creature subsists. Hence is derived their collective title of Foraminifera, from the Latin *foramen*, an aperture.

These Foraminifera abound—as we have already seen—in tropical and temperate sea waters all over the globe. A few forms live upon the sea-bottom, and others at the intermediate depths; but they certainly occur in greatest abundance a few feet below the surface. When they die their shells sink to the bottom, and by their gradual accumulation form the deep-sea mud, which from the preponderance of the genus *Globigerina*, already referred to, is known popularly as the "Globigerina ooze." The inconceivable slowness of this accumulation, may be gathered from the fact that 10,000 shells of Globigerina would hardly cover the space of a square inch.

In addition to the Foraminifera, there are scattered through the Globigerina ooze, a host of other minute bodies. The most peculiar of these are certain objects known as *coccoliths*. Each of these consists of two minute saucer-like discs, united by a common stem. These coccoliths are frequently found aggregated into spheroidal groups known as *coccospheres* (Fig. 5). Less common are the beautifully symmetrical shells of the Radiolaria,† a family group of microscopic organisms closely allied to the Foraminifera, but having shells composed of flinty, instead of limy material (Fig. 4). Lastly, we find fragments of interlacing spicules of sponges, and in some localities, the shells of the lowly forms of plants known as *Diatoms* (Vol. II., p. 277, Fig. 5), which, like the Radiolaria, possess the power of building up siliceous skeletons of great symmetry and beauty.

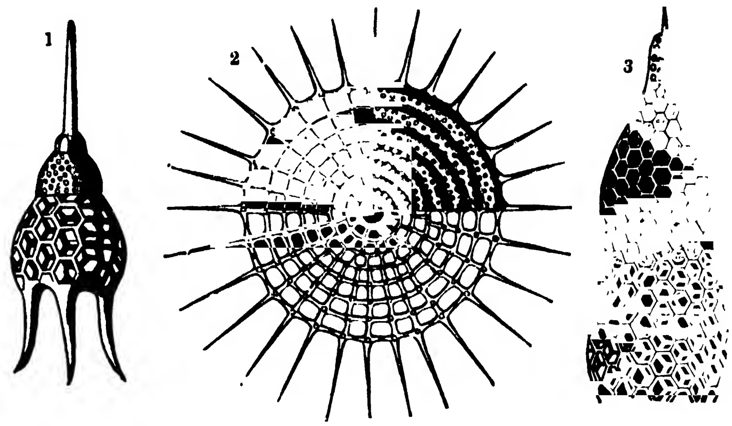


Fig. 4.—Shells of Radiolaria.—1. Podocyrtis; 2. Stylodictya; 3. Eucyrtidium.

Precisely as in the Globigerina ooze, we find in the chalk an abundance of Globigerina, and even the coccolith, the occasional Radiolaria, and the Diatoms; while, as we have already indicated, both deposits have an enormous horizontal extension. But at this point our parallel suddenly ceases. In all their remaining characteristics the ancient chalk and the modern ooze appear to be most strikingly contrasted.

A chemical analysis of a piece of pure chalk shows that it contains from 94 to 98 per cent. of carbonate of lime, and merely a trace of alumina and silica; while a similar analysis of a sample of the Atlantic ooze reveals the presence of only 44 to 78 per cent. of carbonate of lime, at the same time that alumina is present in the proportion of from 6 to 33 per cent., and silica in the proportion of from 5 to 11½. Again, nowhere in any of the deep-sea dredgings has anything been brought to the surface from the Globigerina ooze that bears the remotest resemblance to the flints, which give such a striking appearance to the chalk formation. Until these difficulties are removed, it is manifestly impossible to bring the chalk and ooze into satisfactory parallelism.

The difficulty of the presence of a large excess of non-calcareous mud and volcanic ash in the Atlantic ooze, as compared with the chalk, may perhaps be overcome by the theory that the mud of the ooze is glacier mud spread over the sea bottom

* "Science for All," Vol. III., pp. 78—80, 82, 162—3, 165, 167.

† "Science for All," Vol. III., pp. 82—3.

by the deep-sea currents from the Arctic regions; and that the volcanic dust is derived from the active volcanoes of Iceland—the dust of which occasionally reaches even the British Islands—while, on the other hand, the collective fauna of the chalk shows that the ocean in which it was deposited was comparatively warm, and its high temperature may have been due to the presence of low land to the north, or a submerged ridge sufficiently shallow to prevent the influx of the cold and muddy Arctic waters. But there is no such easy means of escape from the difficulty of explaining how the flint, which is wholly absent from the superficial stratum of the ooze, is so abundant in the chalk formation.

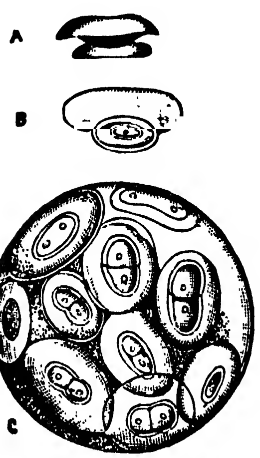


Fig. 5.—A, B, Coccoliths; C, Coccosphere. (*After Huxley and Thomson.*)

Sir Wyville Thomson and Dr. Carpenter, in their dredging expeditions in the *Lightning* and *Porcupine*, made a most careful study of the features of the Globigerina ooze deposits that margin the coast of Europe, from the Färoe Islands to the Straits of Gibraltar. The specimens most frequently brought up from the ooze in these expeditions were examples of siliceous sponges, the skeletons of which are formed of a glassy network of interlacing threads of flint—like that of the well-known Venus flower-basket. As many as forty specimens of these sponges were occasionally taken in a single haul. Some of these vitreous sponges have already been figured in this work.*

Flinty sponges of this type are occasionally met with in the chalk itself—the beautiful cup-like *Ventriculites* being perhaps the best known—but they are by no means common; and, contrasted with the abundance of similar sponges in the ooze, may indeed be said to be excessively rare. Reading this fact in conjunction with what we have already indicated of the differences in chemical composition between the white chalk and the ooze, we see that in the ooze silica is found partly in the form of the skeletons of sponges, and partly disseminated through the mud, while in the chalk formation almost the whole of the silica is restricted to the flints. But were the silica of the flints of the chalk distributed as in the modern formation, the proportion in both would be almost identical. The natural inference is, that if the chalk and ooze are similar in origin, the sponges must once have been present in the chalk, but they have somehow disappeared; and, further, the silica of which they were formed, has, in some puzzling manner, gone to form the flints.

Several scientific men, who have felt themselves shut up to this conclusion, have endeavoured to show how this wonderful transformation has taken place. Under certain processes chemists are able to reduce silica to a jelly-like state; and Sir Wyville Thomson has suggested that by some means or other the silica of the sponges, or of the chalk, had been first reduced to this gelatinous state, and accumulated in any convenient cavities, where it was finally consolidated into flint; but how and why this should happen he did not attempt to explain.

When scientific men first commenced the study of the Globigerina ooze, they frequently found their specimens covered with a soft gelatinous matter (like the white of an egg; or better, like the glairy living matter, found in the interior of the Foraminifera, Radiolaria, and sponges), in which the strange discoid coccoliths seemed to move and float. To this glairy matter Dr. Huxley gave the title of *Bathybius*, or deep-sea animal; and many ingenious theories were started to account for its presence upon the ocean floor, and of its probable relations to the more perfectly-formed creatures existing at great depths. But both animal and theories suddenly disappeared from sight together a short time afterwards, when Mr. Murray, of the *Challenger*, and his associate Mr. Buchanan, showed that this gelatinous matter was, probably, not living matter at all, but a chemical product, due to the action of acid upon the limy sea-water surrounding the specimens of ooze under examination. But Bathybius, though scotched, was not killed, and has been resuscitated with great effect and made to do duty in the formation of the flints.

According to Dr. Wallich, who has for many years past studied the deep-sea deposits of the North Atlantic basin, the Globigerina ooze is covered with a superficial layer of gelatinous matter—the so-called Bathybius—derived from the Foraminifera, sponges, &c. This gelatinous layer, which rises with the increase of thickness of the ooze, dissolves and absorbs the silex of sponges, &c., until at last it becomes super-saturated with silica, and a layer of flint is then deposited.

* "Science for All," Vol. I., pp. 56, 59—61, 63.

On the other hand, according to Mr. Sollas, who has approached the subject from the opposite direction, by a study of the chalk and flints themselves, the horizontal flint beds appear to have been usually formed out of a sheet of sponge spicules. These, under the pressure of the water at a great depth, entered into solution; the calcareous mud around was next partly replaced by silica, and siliceous chalk was formed. Finally, the interstices of this chalk were filled by a simple deposit of silica, and the siliceous chalk was at last converted into solid flint. The flint veins and nodules surrounding organic remains had their origin in the fact that silica, like other minerals, has a tendency to be deposited upon free surfaces. But the entire subject is still extremely obscure.*

Vast as is the region covered by the ancient chalk formation, it is dwarfed into utter insignificance when contrasted with the enormous area covered by its modern parallel, the Globigerina ooze. This is found in all the great ocean basins in the tropical and temperate zones, at depths lying between 250 and 2,500 fathoms. The outer edge of the ocean floor forming the fringe of the land, and extending outwards for a breadth of about 100 miles, is covered with the coarse *débris* derived from the land, while the deepest abysses of the ocean basin are coated with a deposit of red clay of dubious origin, but many of the intermediate areas, forming the main mass of the sea-floor, are covered with the Globigerina ooze.

When the striking resemblances between this ooze and the chalk were first discovered, a few scientific investigators not only leapt at once to the conclusion that the two were identical in origin, and that the chalk was a deep-sea deposit, which must have been laid down in an ocean of enormous depth extending from Britain to the Himalayas, but they went further, and asserted that though the floor of the eastern half of this old ocean has been upheaved, such is not the case with its western half, which still forms the North Atlantic basin, and that in this basin the deposition of ooze has gone on uninterruptedly from the time of the chalk to the present day, so that even we ourselves may be said to be living in the chalk epoch. Now it is impossible to show that the deposition of these white muds has not gone on without intermission in the Atlantic basin since that date; but that we cannot be said to be living in the chalk age from a geological point of view, is abundantly proved by the fact that none of the characteristic chalk animals are now existent; all the species of the higher groups living at that age have become wholly extinct, and their place has been taken by others. Again, it cannot be proved to demonstration that water, having a depth equal to that of the ocean abysses where the great sheets of ooze are now being deposited, did actually extend across Europe in the chalk age, and this question must, therefore, still be regarded as unsettled. Those who still hold that such, indeed, was the case, find themselves confronted with several awkward difficulties. The shell-fish, which we find fossil in the chalk, though differing specifically from modern forms, yet belong to family groups which are, at present, most abundant, not in deep seas, but in comparatively shallow waters, while, at the same time, the characteristic shell types of the Atlantic ooze seem to be generally wanting in the chalk. Again, when the chalk formation of Europe is studied in the field, it is found to get sandier both to the north and south, as if the seas were shallow in these directions, while some of the highest beds of the chalk in Denmark and Belgium have all the appearance of having been coral reefs, which can only be formed where the waters are quite shallow. Not only so, but around the superficial coral reefs of the Pacific and West Indian Islands a soft white mud is being formed at the present day identical with pure white chalk. For these reasons it is urged by some that nothing more than a shallow arm of the Atlantic stretched across Europe in the chalk age. This gulf, into which it has been suggested that the warm waters of the Gulf Stream were then deflected, was at most but a few hundreds of feet deep in its deepest part, and was bordered by coral reefs, from the washings of which was formed the great sheet of chalk whose fragments are now scattered over that area. From the opposite point of view it may be contended that the resemblances between the chalk and the Globigerina ooze are too manifest and vital to be thus easily disposed of. The clear identity of lithological character of the chalk over its great area, the parallelism of its beds, its freedom from foreign admixture, &c., all point unanimously to distance from land and freedom from disturbing currents. The sands and muds that overlie and underlie the chalk itself contain, too, the fossils of those animals characteristic of deep seas. But those who argue that the chalk was laid down in a shallow sea have one crowning argument which is supposed to overwhelm all

* The chemistry of flint is discussed in "Science for All," Vol. IV., pp. 343—351.

opposition. The surface of the great sheet of chalk is almost everywhere worn into deep holes and hollows, and in and upon these rest the more recent clays and sands of the Tertiary period, in which the fossils are all distinct from those of the chalk. Here, then, it is triumphantly pointed out, have we incontrovertible evidence of the shallowness of the sea, in which the highest strata of the chalk were laid down; for in order to originate these hollows the chalk must have been elevated into dry land after its formation, and then eroded by rain and rivers; and it must have remained in this continental state until the gradual changes, which are continually modifying all living creatures, had led to the introduction of new groups of animal forms. Even this argument, however, admits of a satisfactory reply. It is answered by the opposite party that no such elevation could possibly have taken place, or the chalk would have been all worn away. Instead of this being the case, a portion only appears to have been removed, and the surface of the rest is merely worn into insignificant hollows as if by the action of acids. Now, in the deepest parts of the ocean of the present day the calcareous parts of the shells of the Globigerina are dissolved by the carbonic acid present in the waters at great depths, and the actual deposition that takes place in these depths is so infinitesimal in amount that the very dust of shooting stars forms an appreciable fraction of it, and the teeth of animals lie unburied upon its surface for a period long enough for the entire race that yielded them to become extinct. Hence it is not wholly outside the bounds of probability that the line of junction between the chalk and tertiary marks, not an upheaval, but a depression, the surface of the chalk having been partly eaten away by the gases of the deep sea. The length of this period of depression is measured by the change in the life of the highest chalk and lowest tertiary beds, and the absence of intermediate rocks follows of necessity from the fact that no appreciable thickness of sediment was laid down in the interval of depression.

Thus, in spite of the wonderful advances made of late in our knowledge of the resemblances between the chalk and the deposits at present being laid down in the deep sea, many of the difficulties which enshroud the origin of the chalk-beds are to the full as mysterious as ever, and the patient research of many future years is needed before we shall be able to read the true history of a piece of chalk.

THE LEGS AND FEET OF INSECTS.

By Arthur Hammond, F.L.S.

EVERY portion of the structure of insects is replete with examples of the exquisite finish which has been bestowed upon their organisation, and the wonderful adaptation according to circumstances and individual wants which the same organ exhibits in different species. A few illustrations of this, drawn from the feet and legs of common British insects, will form the subject of our present paper.

The simplest mode of progression among insects is that observable amongst maggots, as they are called, or the larvæ of flies. It is here effected without the aid of any special organs at all, as has been already noticed in the case of the larva of the house-fly.* A slight modification of this method is found in the larva of *Ephydra*, a fly frequenting salt marshy situations. It is about one-third of an inch in length, and is conspicuous for its singular forked tail, carrying the orifices of the breathing tubes. The ventral or lower surface of each segment is provided with a pair of little tubercles around, with hooks directed backwards, with which it makes its way along the submerged stems of grass, reeds, &c., amongst which it lives. When about to change into the pupa the larva remains attached to its support by the hindermost pair alone, which are so closely twined around the grass stem as to meet on the other side, and the skin hardening in this position gives to the insect the appearance of being transfixed by the stem, as shown in Fig. 1.

Amongst the simpler forms of locomotive appendages, exhibiting nevertheless the most singular beauty, must be mentioned those of the larva of *Tanypus maculatus* (Fig. 2), another two-winged insect belonging to the crane-fly family. It is a very minute creature, and requires the aid of a microscope to bring out the wonderful details of its structure, which can then be seen through the

* "A House-Fly;" "Science for All," Vol. IV., p. 27.

perfectly transparent skin. Immediately behind the head a soft transparent cylindrical process may be observed to project from the middle line of the body, as soon as the insect has had time to recover from the astonishment occasioned by its capture and transfer to the close quarters of the live-box. This at first appears to end in a blunt termination, but very soon a couple of branches of somewhat smaller diameter are pushed out from the truncated end, while from the extremity of each branch a perfect coronet of recurved hooklets is everted (Fig. 3), the whole process being strongly suggestive of a stocking being turned inside out by the hand and arm being thrust down within it, the place of the hand and arm being, however, supplied by the pressure of the fluid contents of the body. A muscle is seen passing down the centre to each coronet of hooks, by which, as occasion requires, they are withdrawn, first into the branching processes, then these into the central one, and finally the whole into the interior of the body, so completely that not a vestige remains visible, just as the toe of the stocking might be grasped by the hand and drawn in again. The tail is furnished with a pair of somewhat similar but slightly larger processes, capable of protrusion and retraction in the same way. This larva is frequently met with in the decomposing vegetable matter at the bottom of ponds, &c., and is well worth attention from the clearness with which the whole of its organisation may be seen, the entire course of the alimentary canal and the process of digestion being clearly visible, as well as the nervous cord and the pulsations of the dorsal vessel, the muscles too, especially those of the head, show out in brilliant colours under the influence of polarised light. Specimens of a rollicking little crustacean called *Lynceus sphæricus*, their merry gambols all at an end, may be seen oscillating to and fro with the peristaltic motion of the intestine.

The legs and pro-legs of caterpillars are so much better known that a short notice of them here will suffice. We will take those of the caterpillar of the goat moth as an example. This huge red larva, something like a raw animated sausage, has each of the three first or thoracic segments of the body provided with a pair of short conical jointed legs, each terminating in a single claw (Fig. 4*a*). These occupy the place of the future legs of the perfect insect. They are, however, very simple in structure, for although all the joints proper to the fully developed insect leg are undoubtedly present, each of them as yet presents little more than a horny cylinder, connected with the preceding and following joint by a softer intervening membrane, and all regularly diminishing in size from the base to the hooked apex. The pro-legs, or false legs, as they are called (Fig. 4*b*), occur in pairs on the sixth, seventh, eighth, and ninth segments of the body, in addition to which there is an anal pair at its termination, and each consists of a complete circlet of recurved hooks, with the exception of the anal pair, where the circlet is only half complete; they disappear completely during the metamorphosis. The creeping sensation produced by a caterpillar crawling over the hand is due to the action of these hooks on the skin.

We will now pass from these larval forms to the finished limb of the perfect insect, and will take in the first place that of the Water Scorpion, the ferocious aspect of which insect is due to a peculiar modification of the fore-legs, whereby they are diverted from their usual purpose and adapted exclusively for the seizure of their prey. They become, in fact, a sort of hand instead of a leg. To this end the usual proportions between the joints are reversed, and instead of the coxa, the femur (Fig. 5) is the largest joint of the leg, to allow room within it for the powerful muscles which close the next joint, viz., the tibia, upon it, somewhat as the blade of a knife is closed by the spring, while to complete the parallel, the inner edge of the femur is deeply grooved, so as to receive the tibia, much in the same way as the knife-blade is received within the handle. Woe betide the luckless Ephemera larva that comes within the grasp of these terrible pincers. The tibia seems to terminate the foot, there being no appearance of tarsal joints. A slight line across the former, however, and a comparison with the other legs, give rise to the probability that the tibia and the single-jointed tarsus are here united into one piece, to form what may be called the knife-blade. The other legs of this insect are formed for creeping, and present nothing more remarkable than the single-jointed tarsus.*

A very similar formation of the leg occurs also in another insect of the same family, called *Naucoris* (Fig. 6). The latter, however, instead of displaying his weapons openly, as does the Water Scorpion, keeps them discreetly tucked under his chin, where they are doubtless equally serviceable

* It will be seen that most insects possess several short joints in this division of the leg. For the names and sequence of the leg-joints see "A Cockroach:" "Science for All," Vol. III., p. 328.

and not so much in the way, as this insect is a powerful swimmer, its hind feet being modelled as oars on the same plan as those of the Water Beetle, to be hereafter described.

There is an aquatic insect called *Gerris*, often to be seen on the surface of clear running water, whereon it maintains its position against the stream by a series of forward jerks with its long intermediate legs. All of them are densely clothed with hair, exerting a repellent action on the water whereby they do not sink into it, and the insect consequently walks or rather darts forward on its surface. The tarsi consist of two joints, and differ from those of most other insects, in that the terminal hooks or claws are not placed exactly at the end of the last joint, but a little way back at the bottom of a deep notch as shown in Fig. 7. It is not easy to understand the object of this peculiarity.

The tarsi of the great majority of insects are composed of from three to five joints. Of these we shall select in the first place the legs of the Great Green Grasshopper, as it is frequently but somewhat erroneously termed, its scientific name being *Gryllus viridissimus*, and it differs from the true grasshoppers in that the female is possessed of a long sword-like ovipositor with which to deposit its eggs in the ground. The tarsi of this insect, when looked at from above, appear to be distinctly four in number, but when seen from below they as distinctly amount to five (*see* Fig. 8, *a*, *b*). Possibly this may be evidence of a very slow and gradual change taking place in the conformation of these insects, that in long past ages the tarsus consisted of five perfectly separate joints, but that subsequently the two first have become by degrees more and more approximated and soldered, so to speak, together on their upper surfaces, leaving the lower ones still imperfectly united as evidence of the original condition of things. That changes somewhat similar to this do occur in the animal creation seems certain, for a perfect series of fossil forms of the horse family has been discovered, the originals of which possessed distinctly three or four toes, and these by minute gradations pass into the single-hoofed form with which we are at present so familiar. Each tarsal joint is provided with a pair of soft pads or cushions, and in the last joint but one these are very large. But the tarsi do not yield all that is worth notice in the legs of this insect. The fore tibiæ (Fig. 9) are especially remarkable for a pair of oval orifices placed side by side near their upper extremities. They are connected with the main trachea passing down the leg. Their use is unknown. The hind femora are very large to contain the powerful muscles necessary for effecting the leaps of the insect, and a short explanation of the method by which this is effected may perhaps be acceptable to our readers. This portion of the limb contains within it two principal muscles; the adductor muscle by which the limb is bent or flexed, and the abductor by which it is straightened. Both have their origin—as it is called —in the horny integument of the limb, *i.e.*, their fixed ends are attached thereto, while the other extremity ends in a tendon attached to the point requiring motion, where it is said to be inserted. Fig. 10 shows a diagrammatic longitudinal section of the femur, the connection of the muscles, *x*, being the point where the tibia turns upon it, *ad* the adductor muscle, and *ab* the abductor. A very little consideration will show that the pull of the former on the point *d*, must have the effect of bending the tibia, while the action of the latter on *b* must, on the other hand, straighten it. The act of leaping requires the limb to be suddenly and vigorously straightened, and for this purpose it will be noticed that the abductor muscle considerably exceeds the other in size.

The legs of beetles offer a singular variety of curious and beautiful contrivances. As a typical form we may take that of the stag beetle (Fig. 11), and then look at some of the more interesting modifications which others of the same order present. The coxæ, or basal joints of the legs of this insect, are lodged in deep hollows between the plates of the thorax, where they are secure from dislocation by any force, save such as would absolutely crush the insect. This advantage, however, is attended by a great limitation in the play of the joints, they being only capable of a limited amount of revolution, to use a sailor's phrase, in a fore and aft direction. The requirements of the insect, however, demand a certain amount of lateral motion to cause the legs to approach to or recede from the centre of the body, and this is furnished by the articulation of the coxa with the succeeding small joint, the trochanter; the trochanter on the other hand is fixed to the femur and almost seems to form part of it. The femur is a stout smooth piece, and is followed by the more slender tibia, which is furnished especially at its termination with a few short spinous projections. To this succeed the tarsal joints, five in number, exquisitely formed and glittering with an unapproachable polish, the first four being conical, and fitting one

into the other with a cup-and-ball movement; and the last considerably longer, and furnished with the ungues or terminal hooks, which again are allowed a certain freedom of movement within the cup-like cavity from which they take their rise. A slender process terminating in two feathery filaments may be seen between them.

The under surface of the tarsi in many beetles is covered with a pile of curiously-diversified hairs; more especially is this the case with the *Carabidæ*, or ground beetles, the fore, and sometimes the intermediate tarsi of which are frequently adorned in this manner. Fig. 12 represents the extremity of the tibia and the tarsus of one of these insects. The first three tarsal joints, it will be noticed, present a striated appearance, resulting from the close juxtaposition of the edges of a great number of delicate spatulate plates of chitine (doubtless modified hairs) turned towards the spectator. When these are viewed separately under a microscope, they are seen as in Fig. 13. The deep notch near the end of the tibia is another feature worthy of notice.

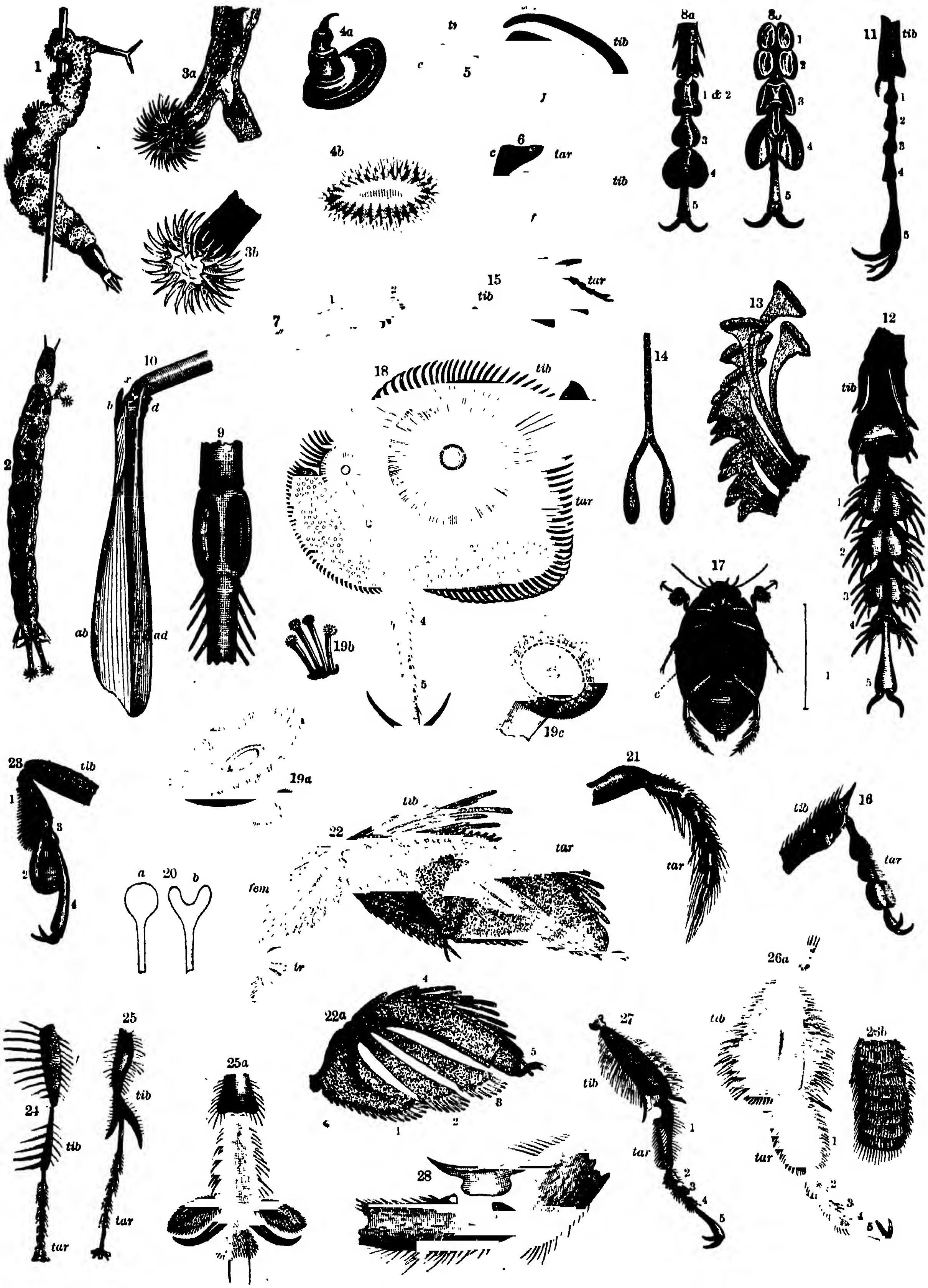
Fig. 14 exhibits a hair from the under surface of the tarsus of *Donacia crassipes*, a pretty little metallic-coloured beetle, found sometimes on the stems of water-plants.

Fig. 15 exhibits the fore-leg of one of the mimic beetles or *histeridæ*, so called because they have a way of contracting their limbs and counterfeiting death when alarmed. They are found in the dung of horses and cows, and the broad stout tibia, with its blunt thorny projections, is well suited for forcing its way through the substance in which it lives, and is well in harmony with the compact form of the whole body, as well as with the elbowed antennæ which are packed carefully away beneath the thorax, to be out of harm's reach.

Fig. 16 shows the foot of a beetle belonging to the great weevil family. It is remarkable for the curious way in which the tarsus is thrust out at right angles from the extremity of the tibia, which ends off blunt, and is furnished with a stout spine bent down over it, which almost precludes the tarsus from assuming the position usual in other insects.

Perhaps, however, the most astonishing structure presented by the feet of insects is that found in certain water beetles. Amongst these, the best known is the foot of the great water beetle *Dyticus marginalis*, doubtless familiar to many readers. We will prefer, however, to take that of a somewhat smaller insect of the same family, viz., *Acilius sulcatus* (Fig. 17), common in ponds and ditches in the neighbourhood of London. The fore-feet of the male in this insect are at once distinguished from those of the female by the great dilatation of the tarsal joints, on examining which from beneath by means of a low power of a microscope, the three basal joints are found to be spread out into a broad flat surface (Fig. 18), across which run two narrow fissures, representing the divisions between the joints, the first of the three areas into which it is thus divided, viz., that formed by the basal joint, being considerably larger than the other two put together. All three are surrounded by a regular fringe of curved hairs, and from the broad surface arises a great number of cup or disc-shaped hairs, frequently but erroneously described as suckers. The great beauty of the spectacle they offer cannot be adequately conveyed by the pencil. The large basal joint, it will be observed, carries one very large disc and two of medium size. A portion of its surface, together with the greater part of the two remaining joints, is beset with a multitude of very much smaller disc-bearing hairs. If we suppose a hair with a bulbous tip, as at Fig. 20*a*, to be thrust in at its extremity, as in Fig. 20*b*, we shall have a good idea of the disc-bearing hairs of the beetle, which, indeed, are in principle only amplifications of those on the pads or pulvilli of flies, as already described (Vol. IV., p. 22), and their purpose is somewhat similar in both cases, viz., to enable the insect to adhere to a smooth surface, by means of a viscid fluid which exudes from the membranous discs of the hairs, with the more exclusive object, however, in the case of the beetle, of enabling the male to seize and to retain the female during the breeding season. It will be noticed that the discs are marked with chitinous ridges, radiating from the centre to the circumference, and giving them a very pretty appearance. That the discs are not, as was formerly supposed, suckers, has been very conclusively shown by Mr. Lowne, who caused one of these insects to adhere to the interior of an air-pump receiver. Upon exhausting the air the insect remained attached, which of course could not have happened if the discs had really been suckers. The last two tarsal joints are of the form usual in other beetles.

The intermediate legs of *Acilius* offer nothing remarkable, but the hind legs again deserve some share of our attention. In the first place we must notice that the coxæ (Fig. 17) are enormously enlarged, to allow room for a great mass of muscle,



VARIOUS PARTS OF THE LEGS AND FEET OF INSECTS.

(*Explanation of Figures will be found on pp. 78—9.*)

so much, indeed; that they almost seem to form more properly a part of the body-wall of the insect, than to be the basal joint of the leg. The tarsi again (Fig. 21) are clothed with long hair, and are destitute of terminal hooks, whereby, in conjunction with the powerful muscles of the coxæ, they are enabled to act as oars to propel the insect through the water.

The whirlwig beetle (*Gyrinus natator*) is, perhaps, one of the commonest of common objects of the country, familiar, indeed, to every child, yet few are aware of the many claims to interest it possesses. In passing we may remark that it has four compound eyes—two on the top of its head to keep a sharp look-out against danger from above, and two beneath to peer down into the depths after its prey. But our immediate interest is with the legs, the anterior pair of which do not offer anything remarkable; but the two hinder pairs are unique, being formed on the following plan. The trochanter, the femur, and the tibia are broad, flat, triangular pieces (Fig. 22), narrow at the base, and broadening to the extremity, and connected together by their outer angles. The first tarsal joint, however, is attached to the extremity of the tibia by its inner angle, being just the reverse of what occurs with the preceding, and together with the two following is produced on the inside into a long, flat, leaf-like lobe. The fourth joint is long, flat, and crescent-shaped, and at its extremity it bears a minute terminal joint with its pair of hooks. The thin lobes of the first three tarsal joints, together with the fourth, fold over each other much as did the leaves of the little ivory tablets formerly used for writing memoranda, being connected together by a pivot at one end. When expanded, they must present a very broad surface to act against the water in which they are immersed, while the body of the insect, as is well known, floats on the surface. This peculiar conformation of the legs is doubtless intimately connected with the power the insects possess of shaping their course in the mazy circles which render them so conspicuous. It is obvious that if the tarsal lobes of one side were expanded, while those of the other remained closed, the insect would be pulled round toward the closed side, just as a strong oarsman on one side of a boat would pull round a weak one on the other. But it is to be observed that no muscles are discernible in the tarsal joints, while those of the femur and tibia are conspicuously seen through the transparent integument. We must not omit to mention that the tarsi are fringed with long, transparent, flattened hairs, as shown in the drawing, serving doubtless to increase their surface.

The foot of the ladybird (Fig. 23) consists apparently of three tarsal joints, the two first of which are clothed beneath with a dense pile of hairs. The last joint, it must be noticed, springs from near the base of the second, and not, as usual, from its extremity; also, if looked at closely, it will be found that, though apparently a single joint, it really consists of two, a very short one intervening at its base, so that the tarsus really consists of four joints, and not three, as at first sight it might be thought.

The legs and feet of flies present a general resemblance to that previously described in the case of the house-fly. Various peculiarities, however, may be noticed in them, such as the very long spines with which the femur and tibia of *Cordylura spinimana* (Fig. 24) is armed, and the thick, strong terminal spine of the tibia in *Bibio marci* (Fig. 25), a large black fly found on herbage in May or June. This last also, together with some others, has three pads or pulvilli instead of two.

The foot of the humble-bee is shown in Fig. 26, with its pollen plate (*a*) and pollen brush (*b*). Mr. Westwood tells us that the pollen plate "exists on the outside of the hind tibia and basal joint of the tarsi of the neuter hive and humble bees, which are rather hollowed out, and in which species it is employed to carry pollen grains which have been saturated with honey." It will be seen that the smooth surface of the joint is fringed with long curving hairs, forming a receptacle for the pollen. The basal joint of the tarsus is greatly enlarged, and is closely set with hairs, forming the pollen brush used for collecting that material. Fig. 27 shows the fore tibia and tarsus of a smaller species of humble-bee. The tibia is armed at its extremity with a strong tooth-like process on the outside of the joint, and on the inside is a movable spur, having a thin horny blade. The first tarsal joint has at its base a deep notch, against which the blade of the spur closes (Fig. 28). It is said that the insect makes use of this apparatus in hackling its moss and building its cell.

EXPLANATION OF FIGURES.

Fig. 1.—Larva of *Ephydra* attached to Grass Stem.
Fig. 2.—Larva of *Tanypus maculatus*.
Fig. 3*a*.—Anterior Foot of ditto, with Recurved Hooklets. The Hooklets in one Process are shown withdrawn.
Fig. 3*b*.—Posterior Foot of ditto.
Fig. 4*a*.—Thoracic Leg of Caterpillar of Goat Moth.

Fig. 4b.—Proleg of Caterpillar of Goat Moth.
Fig. 5.—Leg of Water Scorpion. In this and succeeding Figures the following letters are used: *c*, Coxa; *tr*, Trochanter; *f*, Femur; *tib*, Tibia; *tar*, Tarsus; the Tarsal Joints are indicated in their order by numerals.
Fig. 6.—Leg of *Naucoris*.
Fig. 7.—Tarsus of *Gerris*.
Fig. 8a.—Ditto of Great Green Grasshopper, Upper Surface.
Fig. 8b.—Ditto, Under Surface.
Fig. 9.—Orifices in Anterior Tibia of Ditto.
Fig. 10.—Section of Hind Femur, showing Muscles; *ad*, Adductor; *ab*, Abductor; *d*, *b*, the Points of Insertion of each respectively; *x*, Fulcrum.
Fig. 11.—Foot of Stag Beetle.
Fig. 12.—Ditto of Ground Beetle.
Fig. 13.—Spatulate Hairs from ditto.
Fig. 14.—Bifid Hair from Tarsus of *Donacia crassipes*.
Fig. 15.—Leg of Mimic Beetle.
Fig. 16.—Ditto of Weevil.
Fig. 17.—Water Beetle (*Acilius sulcatus*), Under Surface, showing Patellated Tarsi of Fore-legs, and Enlarged Coxæ (*c*) of Hind Legs. Slightly enlarged.
Fig. 18.—Fore-leg of Ditto, magnified. The enlarged portion upon which the Discs are situated consists of the first three joints of the Tarsus.
Fig. 19a.—Large Disc viewed sideways, to show Pedicel.
Fig. 19b.—Group of small Disc-bearing Hairs.
Fig. 19c.—Small Disc, highly magnified.
Fig. 20.—Diagram to illustrate Conversion of a Bulbous Hair into a Cup or Disc.
Fig. 21.—Hind Foot of *Acilius sulcatus*.
Fig. 22.—Hind Leg of Whirlwig Beetle. The Muscles are seen through the Integument in the first three joints.
Fig. 22a.—Tarsus of Ditto, the Joints being shown expanded.
Fig. 23.—Foot of Ladybird.
Fig. 24.—Leg of *Cordylura spinimana*.
Fig. 25.—Ditto *Bibio marci*.
Fig. 25a.—Foot of Ditto, showing three Pulvilli.
Fig. 26a.—Hind Leg of Humble Bee, showing Fringed Tibia or Pollen Plate, and Enlarged Basal Joint of Tarsus.
Fig. 26b.—Reversed Side of Basal Joint of Tarsus, showing Pollen Brush.
Fig. 27.—Fore-leg of Small Humble Bee.
Fig. 28.—Blade and Notch of Ditto.

COAL-TAR.

BY WILLIAM DURHAM, F.R.S.E.

DIRT has been defined as "matter in the wrong place," and if ever there was a substance which deserved the name of dirt, that substance is coal-tar, which we have already briefly noticed in discussing the nature of coal-gas.* It might well be described in Scriptural language as "broth of abominable things." Black, sticky, greasy, emblem of all that is defiling, it has passed into the proverb, "You cannot touch pitch and not be defiled." If we touch it, it sticks to our fingers or clothes like a leech, and we carry about with us for days its sickening stench. It cannot be washed away, as it floats on the surface of the water, ever ready, like the cuttle-fish, to seize in its disgusting embrace whatever comes in its way. Nothing but fire effectually destroys it, and we are tempted to consign it to the flames as an unclean thing.

But ere we do so, let us for a moment think, May it not be matter in the wrong place? Can we not find out that niche in nature's fabric which it is fitted to fill? Let us see what the chemist has to say to the matter. We may be well excused a little incredulity when he tells us that with the aid of that filthy liquid the charms of the fairer portion of humanity may be greatly enhanced. We may be apt to conclude that if it is so, it must be among the dusky beauties of the South Sea Islands, who prefer striking effects to artistic design, rather than among the fair daughters of England, or Scotland, or America. The wizard hand of the chemist, however, works many wonderful changes, and doubtless in this case he may make good the statement we have made.

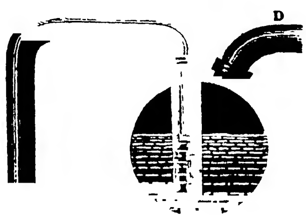
By many the chemist is looked upon as a rather "uncanny" individual, who works among green and blue lights, producing somewhat miraculous results by a species of legerdemain, or it may be *diablerie*. We shall endeavour to show, however, that he is not very different from ordinary mortals, and that his methods of working differ from those of other men only in the tools he employs; the principles are the same.

Suppose an antiquary finds amidst a heap of rubbish a dirty-looking body, but having an artificial shape. He takes it out carefully, and clears away the outer crust, and perhaps notes a corner glistening with metallic lustre. Patiently he cleans and rubs, and bit by bit the metal comes out. It looks like pure gold, with some device upon it. Again he cleans, and, behold, a head; yes, at last there it is—the head of an emperor, with the superscription, "Cæsar Imperator," &c. He has unearthed a gold coin of "The Great Empire." Now, the chemist proceeds on exactly the same plan; he separates and polishes after his own fashion, but he does more: he does not throw away the various coverings, but puts them on one side till he finds a place for each, and, like the lapidary or the jeweller, he polishes, and cuts, and sets in various styles the jewel he may find, till he brings out all its beauty and usefulness. His tools

* "Science for All," Vol. IV., p. 172.

only are different. Instead of the grinding-stone and the polishing-powder, the gold or the silver, he uses his acids and his alkalis, and other substances that may be useful for his purpose.

Let us see, then, how these principles are applied to the examination of the substance we are to consider. Coal-tar, as is well known, is a waste product in the manufacture of illuminating gas. The gas coals are placed in a closed iron or earthenware retort, which is then exposed to the heat of a furnace; the volatile constituents of the coal are driven off by the heat, and pass from the retort by a pipe into a second vessel partially filled with water, called a hydraulic main. Here the oily impurities are condensed, forming what we call "coal-tar," while the purif'ed gas passes onward to the other parts of the gas-making apparatus. Fig. 1 will give an idea of the arrangement, —A is the retort; B, the pipe leading to the hydraulic main; C, the hydraulic main, where the tar is condensed; and D, the pipe leading from it to convey the purified gas.



It is very easy to show by burning coal-tar and collecting the products, that it is mainly composed of carbon, as we might imagine from the source whence it is derived, together with hydrogen, nitrogen, and oxygen gases, and sulphur. This mode of procedure, however, would not give us much information, so far as utilising the substance is concerned.

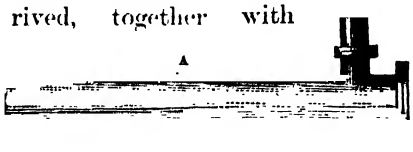


Fig. 1.—Retort for Distilling Coal-tar.

We want to know how these substances are arranged in the compound body, for much will depend on this. In arithmetic, for instance, we may have only the figures 1, 2, and 3 to deal with, but the value of the sum represented will entirely depend on whether we arrange them as 123, 213, or 321. So with the constituents of coal-tar. We must, therefore, adopt some plan by which we shall know how the carbon, hydrogen, &c., are disposed.

We shall arrange, then, our inquiry into two departments: first, the separating process, and second, what we may call the polishing and setting. One method, much resorted to by chemists to separate various substances one from another, is what is called fractional distillation, and it is well we should clearly understand its principles. A common iron kettle or boiler may be taken as an illustration. We all know that most water in common use contains some solid matter in solution. Now, when the water is boiled it rises as steam, and leaves behind it the solid matter as a crust on the kettle. We may see this any day. If, instead of allowing the steam to be dissipated into the air, we conduct it by a tube into a cold bottle or other vessel, it is condensed into water again, and we find the water so condensed to be very much purer than it was before the boiling and condensing. In fact, we have separated by distillation the pure water from its solid impurities. It is not necessary, however, that the impurities be solid; they may be liquid, but if so, their boiling-point must be either much higher or much lower than that of water itself, if we are to separate them by distillation. If they have the same boiling-point, they will distil or rise in steam along with the water, and condense with it, so that there will be no separation; but if their boiling-point is lower than water, they will come away first and leave the water behind; or, if their boiling-point be higher, the water will come away first. Thus, suppose we have three liquids mixed, whose boiling-points are respectively 100°, 200°, and 300° Fahr. It is evident we can separate them by raising the mixture first to 100° or so, when the first will rise as vapour, and may be condensed; then raising the temperature to 200°, we shall get the second liquid, while the third will be left behind.

This method of fractional distillation has been applied to the analysis of coal-tar with most wonderful results. The coal-tar is first separated into *pitch* and *tar-oil*. The latter is then re-distilled at various temperatures and submitted to various processes, by which we get from it an almost endless variety of substances. A mere list of these, with their composition and boiling-points, would almost fill a page of this work. We shall, however, confine our attention to four or five which have hitherto proved most useful and interesting. We do not mean to say that the substances in question actually exist in coal-tar as separate bodies, but only, if we may so speak, potentially: that is to say, the application of heat to coal-tar breaks it up, and forms these various chemical compounds.

For many years the pitch got from coal-tar was only useful for the formation of artificial asphalte, and in the manufacture of black paints and varnishes,

while the tar-oil was only useful for "creosoting" timber. Of late years, however, by the persevering industry and ingenuity of chemists, these comparatively useless materials have been made the basis of an entirely new manufacture, which promises to increase still further in importance and value.

Having separated, by means of distillation, &c., the various constituents of coal-tar, we now proceed to study the various polishing and setting processes by which the result referred to has been brought about.

In the year 1856, Mr. Perkins was endeavouring to form artificially the well-known medicinal substance "quinine." In his experiments he was fortunately led to try the effects of bichromate of potash on *aniline*, which is one of the numerous products of coal-tar distillation. He did not succeed in producing quinine, but, instead, got a dirty-looking, sooty precipitate of a very unpromising appearance. If the reader has access to any museum where coal-tar products are to be seen, an examination of this precipitate will greatly enhance his idea of the credit due to Mr. Perkins for perseveringly investigating the properties of this accidentally-produced substance. He was, however, amply rewarded for his labours, for he found, after submitting it to purifying processes, that it gave rise to a most beautiful purple dye, which he named *mauve*. This was the first gleam of the gold that lay hidden under the dirty exterior of coal-tar. There was one great drawback to the use of this dye on a large scale, and that was the small quantity of aniline which could be extracted from the tar. With characteristic energy Mr. Perkins set himself to overcome this difficulty. Aniline is composed of carbon, hydrogen, and nitrogen. Now, there is another product of coal-tar, got in large quantities, named *benzol*, a substance known to many as useful in removing stains and grease from wearing apparel. This benzol is entirely composed of carbon and hydrogen, in much the same proportions as they exist in aniline. Now, the problem was to change this benzol into aniline by adding the nitrogen and a little extra hydrogen. This is accomplished by first acting on benzol with strong nitric acid, when a compound named nitro-benzol is formed, from which aniline can be extracted by a further chemical process, which need not here be detailed. By this fortunate discovery Mr. Perkins at once opened up a new industry, and accomplished the first of a series of most brilliant chemical triumphs. Works were at once erected for the production of nitro-benzol and aniline, which in their turn, as we shall see, gave rise to new products.

A beginning having been made to the manufacture of colouring matter from coal-tar products, chemists were not slow to continue and extend the process. Curiously enough, the next step forward was due to the fact that benzol had been taken as the source of aniline. We have mentioned two products of coal-tar distillation, viz., *aniline* and *benzol*. We direct attention now to a third, named "toluol," like benzol in being composed entirely of carbon and hydrogen. This toluol has a boiling-point not very greatly different from that of benzol, so that in the commercial manufacture of the latter substance, where the niceties of chemical research are not necessary, a small quantity of toluol comes over with the benzol as an impurity. To this accidental impurity the discovery of the next dye is due. When aniline made from this impure benzol is acted upon by a fuming liquid called "tetrachloride of tin," we get the beautiful crimson-coloured dye, well known to every one, called *magenta*. This result is not got when pure aniline is used. We thus see the importance of every little impurity that may be present in chemical manufactures.

Magenta, although a most beautiful and useful dye of itself, is even of more value as a source, or rather raw material, for the preparation of other dyes. It is now manufactured in immense quantities for this purpose, and from some of the residuary products dyes of varying tints have been obtained. One of these, named *phosphine*, is of a beautiful orange tint, and from it and magenta we can get scarlet. By heating magenta with a further quantity of aniline, a beautiful blue colour, called *bleu de Lyon*, is obtained.

In studying this fact of the production of blue from the action of aniline on magenta, Dr. Hoffman was led to substitute other bodies for the aniline, and by this means he greatly extended the number of available colours derived from this source. The substances used by Dr. Hoffman were the iodides of ethyl and methyl. When either of these bodies is heated with magenta, various shades of violet and blue are produced, according to the quantity of iodide used. One of the most valuable results he obtained was the production of a brilliant green. To obtain this, the quantity of iodide must be carefully attended to. This green is one of the most natural colours of the whole coal-tar series, and is as beautiful a colour by gas-light as by day-light.

From the residuum from some of the processes

for obtaining blue shades, a very intense black is obtained. Thus, from these three products of coal-tar, *aniline*, *benzol*, and *toluol*, the chemist, by various processes of purifying, mixing, and combining, gets various shades of blue, violet, green, orange, crimson, scarlet, and black: surely a goodly crop of fruit to encourage further investigation into this endless storehouse of valuable products. We are by no means, however, at the end of our discoveries. Among the bodies obtained by the distillation of coal-tar, there is one of considerable importance in many ways, familiarly known as carbolic acid. This substance crystallises in colourless prismatic needles, which melt to an oily liquid, with a very penetrating odour and burning taste, and attacking the skin of the lips. One of the most interesting properties of carbolic acid is its action upon animal matter. It coagulates albumen or white of egg, and is a powerful antiseptic, preserving meat, &c., most effectually, and even removing disagreeable odours from such substances after decomposition has set in. Mr. Crookes used it with much effect in staying the ravages of the cattle plague. In dressing wounds and sores, also, it renders very great service in preventing suppuration and other evils. We are all familiar with it in its soothing influence upon toothache. It is used also in the manufacture of carbolic acid soap, where its action on the skin and disinfecting properties are found to be of great utility.

Like the other products of coal-tar which we have examined, carbolic acid, besides the useful properties already mentioned, is a source whence various colours may be produced. When acted upon by nitric acid, carbolic acid yields a pale yellow substance, named picric acid. This dyes silks in a most effective manner, the yellow colour being deeper than that of the picric acid itself. In combination with potassium, this acid forms a fine yellow salt, which is extremely explosive, and it has been proposed as a substitute for gunpowder in the charging of shells. From this fact considerable alarm was felt some years ago by many when it was known that some of the brightly-coloured socks then in fashion were dyed with compounds of picric acid, and alarming visions of explosions under one's feet made the wearers of these articles "shake in their shoes." As picric acid has a very bitter taste, it was thought it might be an improvement upon hops in the manufacture of bitter beer; but the public might imagine that this was only transferring the danger of explosion from the feet to the stomach, and rather a questionable improvement. Besides the yellow picric acid, carbolic acid, by the action of other chemicals, gives rise to various shades. Thus, by acting on it with a mixture of oxalic and sulphuric acid, a new body of great interest is produced, named rosolic acid, or aurine. This aurine is a brittle resinous substance, having a slight green metallic lustre. Its solutions are of an orange colour, but change into a most magnificent crimson on the addition of alkalis, such as soda, potash, or ammonia. This colouring matter has not been so much applied in the arts, owing to its easy solubility in water.

Besides the substances we have named as sources of colour, there are many others of much interest, from which beautiful shades may be got, but they are neither so well known nor so thoroughly under control as to be useful in the dye-works. It cannot, however, be doubted that future researches will discover their properties thoroughly, and find a place for them also.

There are points of interest regarding the application of these coal-tar colours to the arts which merit some attention. They are for the most part compounds of carbon, hydrogen, and nitrogen, and are generally what are called "organic *bases*," having properties which are opposite to those of acid; while vegetable colours, on the other hand, which have hitherto been used for dyeing purposes, are for the most part composed of carbon, hydrogen, and oxygen, and possess weak *acid* properties. It is therefore to be expected that in their application some change in the mode of treatment would be necessary, and some difficulties would be encountered. In using vegetable colours, mordants had to be used; that is, some body having the property of fixing the colour in the fibres of the material to be dyed. Now, these coal-tar colours have such an affinity for silk and wool that no such thing as a mordant is required. All that is necessary is simply to dip the silk or wool in a bath of the colour, and it is rapidly dyed. The very ease, however, with which the dye adhered to the fibre was a source of difficulty, as it prevented the dyer from obtaining an even colour, especially with lighter shades, in many cases. This difficulty was overcome in some instances by mixing with the dye a soap lather or a little gum, which prevented the dyeing process proceeding too rapidly, so that it was much more under control, the soap or gum being afterwards washed out with steam or acidulated water. In printing patterns on silk, advantage is taken of the action of some substances on magenta, and colours derived from it. These substances

form, with the magenta, colourless compounds. All that is required, then, is to print on the magenta-dyed silk a pattern with one or other of these substances, when the colour is immediately destroyed, and we have a colourless pattern on a magenta ground. This process can be so modified as to print various colours on one piece of silk.

In dyeing cotton goods, the difficulties were much greater, for although cotton, like silk and wool, was quickly and beautifully dyed by simple immersion in the dyeing solution, yet it was found it would not bear washing with hot water and soap, the colour being almost entirely removed by such treatment. The ordinary mordants—such as alum—used in vegetable-colour dyeing had no effect in fixing the coal-tar colour. After some time Mr. Perkins overcame this difficulty by soaking the cotton in a decoction of tannin in a solution of stannate of soda or alum before applying the colour. The tannin forms with the dye an insoluble compound, and thus the colour is fixed in the cloth. In calico-printing, the mordant used is a solution of arsenite of alumina in acetate of alumina, by which patterns in a great variety of colours can be worked, and it is suitable for all the aniline colours, yielding great beauty and variety of shade. We thus see that in every step of this new industry new processes had to be invented to overcome new conditions of working, but the result has been most encouraging; quite a revolution has been made in the arts of dyeing and printing; processes have been simplified, and varieties have been increased to an almost unlimited extent. Coal-tar colours have been applied with much success to other useful purposes besides dyeing and calico-printing. They have been used as lakes or pigments in combination with alumina. Difficulties had to be overcome in this department also; but skill and perseverance met with the usual reward of ultimate success, and now printing-colours of great beauty and brilliancy are in extensive use. The arts of lithography, type-printing, paper-staining, &c., are all greatly indebted to the products obtained from the distillation of coal-tar.

The most important result obtained from the investigation of coal-tar products, however, remains to be noticed. Of all the vegetable dyes in use, one of the most valuable is derived from the madder-plant, which grows in various parts of Europe, and is cultivated for the sake of this dye. It is extensively grown in Holland, France, Turkey, Italy, and Southern Russia. Its cultivation was attempted in this country, but with no great success. Its importance may be inferred from the fact that the value of the madder consumed is between one and two million pounds sterling per annum. Now, the colouring principle to which madder chiefly owes its value as a dye is called *alizarine*, and is, like many of the coal-tar products, a hydro-carbon: that is, composed of carbon and hydrogen; and the question very soon suggested itself to chemists, Could not some of the coal-tar products be made to yield, or be changed into, alizarine? Many were the attempts made before success was attained; but at length it was accomplished. We mentioned that the first process of distillation of coal-tar gave us as a result pitch and tar-oil, and from the latter we derive all the substances hitherto treated of. Now, by applying the process of distillation to the pitch, we get a hydro-carbon, called *anthracen*, which contains carbon and hydrogen in very nearly the same proportions as in alizarine. This anthracen can be got also from the tar-oil, but not in the same quantity as from the pitch. To this substance, then, the chemists turned their attention. Besides carbon and hydrogen, alizarine contains oxygen. What was required to be done was to take away from the anthracen what are called two equivalents of hydrogen, and add four of oxygen. Various plans were adopted, and patents taken out for the production of alizarine. Generally speaking, each new plan was an improvement on its predecessor, and now the artificial production of this valuable dye is an established industry, doing business to the extent of nearly three-quarters of a million pounds sterling annually. From this alizarine we get most of our red and purple-coloured dyes, Turkey-red being one well-known alizarine colour. Of course this artificial production of alizarine had a serious effect upon madder cultivation, and fears were entertained that the latter might be extinguished altogether; but it is doubtful if this will be the case, as new uses are always found for substances that are cheaply and plentifully produced. However this may be, Great Britain has great reason to be satisfied with the progress of this industry, as well as with that of the aniline colours, as she is the great coal-tar producer of the world, and whatever increases the value of this substance adds greatly to her wealth, and gives employment to her teeming millions of workers, thus giving her a great advantage in that struggle for existence which seems to be a necessary law of our being. An idea of the vast quantity of coal-tar produced may be inferred from the fact that

the London gas-works alone produce no less than 60,000 tons every year. Neither is it at all likely that we have exhausted the capabilities of coal-tar. Of the sixty or seventy distinct substances derived from it already known, only five have been utilised, viz., *aniline*, *benzol*, *tolnol*, *carbolic acid*, and *anthracen*, besides pitch itself, in the industries we have described. What the others may yet accomplish time alone will show.

It is worthy of note that the development of the coal-tar industry is entirely the fruit of abstract and theoretical chemistry. Many so-called practical men are in the habit of lightly esteeming abstract research and theories as of little value in the business of life. To such the discovery of the coal-tar colours is fraught with valuable lessons. The bodies we have referred to as the source of these colours were for many years merely chemical curiosities. Thus benzol, for instance, was discovered by Faraday long before its commercial value was thought of. Had it not been for his and the researches of other chemists, coal-tar might still have been only a useless and disgusting nuisance, instead of a source of wealth and beauty. It is true that the first discovery of colour products was accidental; but the accident was due to the researches of a chemist into an interesting scientific problem, while the further progress was entirely due to systematic investigation, based on what is known as the theory of types. This theory may be somewhat understood by considering the familiar substance, water, which chemists represent by the formula $\left.\begin{matrix}H\\H\end{matrix}\right\} O$, which means that it is built up of two atoms of hydrogen and one of oxygen; and it also suggests that one or both atoms of hydrogen may be replaced by other elements, or by what are called organic radicles. Substituting, for instance, for one of the atoms of hydrogen a radicle called ethyl, we get a substance with formula $\left.\begin{matrix}H\\C_2H_5\end{matrix}\right\} O$, well known to many under the name of alcohol. There are various other types containing three or more atoms of hydrogen, each or all replaceable by other bodies. Now, it was on this theory that Hoffman and others conducted their experiments. Taking the coal-tar bases, and substituting for the hydrogen they contained various radicles, in one or more proportions, he produced the various shades of violet, blue, &c. The brilliant results obtained, therefore, were no mere chance productions, but the natural outcome of intelligent and systematic research.

In this paper we have not entered into the details of manufacture, nor into the various improvements which have been from time to time introduced into the various processes of production. We have rather traced the historical progress of one of the most remarkable chemical achievements of modern times, as illustrating the value of scientific principles in their application to the wants of every-day life. We have seen this black, dirty waste cleaned and polished, and set, like a veritable black diamond, until it reflects all the colours of the rainbow, from the deep reds of alizarine up through the crimsons, the greens, the purples, and the blues of aniline and its derivatives. When we gaze upon the dazzling splendours of the ball-room, with its rustling silks and its brilliant and varied colours, we are reminded that much of it is due to the patient researches in the quiet laboratory, changing the black, uncomely coal-tar of our gas-works into "a thing of beauty and a joy for ever"—or, at least, for a reasonable length of time.

WEATHER-SIGNS AND WEATHER-CHANGES.

By the late Robert James Mann, M.D., F.R.C.S., F.R.A.S., etc.

If it be true, as has been stated in a previous page of this work,* that the wind has more to do with the vicissitudes of the weather than even the prevalence, or deficiency, of sunshine, it follows that this subtle agent may be looked upon as a very significant and useful premonition of the changes that are at hand, and that the shiftings of the wind may be accepted, when properly interpreted, as the most trustworthy of all weather-forecasts. That this is the case is, indeed, a matter of common notoriety. Every one who gives any attention to the subject is perfectly aware that in England a south-west wind is accompanied by a soft, genial temperature, and that a north-east wind is characterised by chilliness and cold. The reason for this is, of course, the obvious one that the

* "How Sunshine Warms the Earth:" "Science for All," Vol. II., p. 124.

south-west wind brings with it the warmth which it has imbibed from the southern expanses of the sea, whilst the north-east wind has just passed over land that is comprised within the cold high latitudes of the earth. With a south-west wind, the inhabitants of England are enveloped in an atmosphere that belongs properly to the more genial climates of the south; with a north-east wind they are wrapped in an air-investment that belongs to the frigid plains of the north, and occasionally even to the frost-wastes of Lapland.

The barometer derives its well-known and thoroughly deserved reputation as the best of all weather indicators from the circumstance that it deals essentially with this great moving-spring of meteorological vicissitude. As a matter of fact, it is the wind, rather than the rain, which the upward and the downward movements of the mercurial column give intimations of beforehand. The rain is but a secondary issue which is incidentally associated with the wind. This, however, is so important an element in what may, perhaps, not inaptly be termed the dynamic mechanism of the weather, that it requires some further notice in this place.

The barometer, it will be remembered, indicates the pressure, or weight, of that portion of the atmosphere which is at the instant floating above the place where the instrument is. When the column of mercury in the tube is sustained at the height of thirty inches above the surface in the cistern, this implies that an air-column of the same transverse dimensions, but extending up to the summit of the atmosphere, at the same instant there weighs fifteen pounds.* If, then, the mercury in the tube sinks to twenty-nine inches, the fall of one inch indicates that the column of air weighs only fourteen pounds and a half. The air has become lighter, to that extent, over the place. The change in the weight of the superincumbent air may have been brought about in either of two ways. It may be simply due to the air having expanded itself to a further outward extent, or higher elevation, and to its having then overflown the denser and less rarefied portions around until as much as half a pound by weight has been taken off from the part of the cistern upon which the column of equal area rests; or, it may be caused by the circumstance that a heavier specimen of air has pressed in until it stands over the barometer, and so has taken the place previously occupied by the lighter one. In either case it is the downward pressure, or weight, of the air that is indicated by the barometer; but in the latter contingency, which is of the more frequent occurrence, change in the height of the mercurial column of necessity, and obviously, indicates movements in the air, or in other words wind.

A rise in the column of the barometer thus shows that heavier air is drifting in to the place just before occupied by lighter air. But as heavy air is almost certainly air that has been condensed by cold, a rise in the barometer indicates that it is a cold wind which is blowing. A fall in the column, on the other hand, shows that light air is arriving at a place just before occupied by heavier air, or, in other words, that it is a warm wind which is blowing. In the lower latitudes of the earth, where the movements of the atmosphere are less interfered with by incidental disturbance than they are in colder climes, this is so certainly the case that change from warmth to cold, or from cold to warmth, may almost as well be inferred from the indications of the barometer as from those of the thermometer—the proper instrument for measuring temperature. In Natal, where the writer of these lines had the opportunity of closely studying the meteorological conditions of the air during some years, the coast of the great African continent trends from south-west to north-east, and has the comparatively cool spaces of the ocean lying towards the south-east, and the sun-scorched highlands of the interior towards the north-west. In this situation the north-west land wind is invariably attended by a falling, or low, barometer, whilst the south-east sea-breeze is as constantly marked by a rising, or high, barometer. In England a somewhat similar condition commonly obtains—although not with the same constancy and regularity—on account of various secondary causes of disturbance which there come into play—the south-west wind, which sets in from the Atlantic, where the currents of the water flow from the sun-heated south, being usually accompanied by a falling barometer, whilst the north-east wind, which comes from the cold northern plains of Europe, is attended by a rising barometer.

But the falling barometer in England is looked upon as the harbinger of approaching rain, and the rising barometer as the sign of fine weather. This, it will be observed, is exactly what should be in accordance with the statement just made, that it is wind, rather than rain, that is primarily dealt with by the barometer. The rain in the case alluded to is an incident, or consequence, of the wind. The

* "Why the Wind Blows:" "Science for All," Vol. I., p. 324.

warm south-west wind, which is the cause of the fall in the barometer, comes from the broad basin of the ocean, heavily laden with the vapour which it has imbibed during its passage over the surface of the water, and it is this which is thrown down as rain as soon as the air is chilled by contact with the cooler land. The cold north-east wind, on the other hand, having been drifting for a long distance over the land, is already a dry wind, which has no moisture to spare. A falling barometer is thus in England an augury of approaching rain, because it is produced by a wind that comes off the sea, and that is the carrier of moisture; whilst a rising barometer is a sign of dry weather, because it is caused by a dry wind, which is destitute of vapour. The change which is experienced in the character of the weather is really due to the circumstance that the inflowing current of air is either warmer or colder, or damper or drier, than that which was prevailing before.

The French meteorologist De Luc, who was one of the first observers that made any attempt to explain the operation of the barometer, conceived that its oscillations were entirely due to the varying amount of vapour held in the air. This was, however, unquestionably a mistake. If this were the correct interpretation of the matter, it should be a *moist* and not a *dry* air which *raises* the column of the mercury. De Saussure, the eminent Swiss physicist, drew attention to this misconception, and demonstrated very clearly that the oscillations are not by any means mainly due to the amount of vapour. Dalton and Gay Lussac agreed in this, and ingeniously proved that when water evaporates quietly in the open air, the vapour ascends through the interstices lying between the air particles exactly as it would if it were rising into an empty space, and without in any way influencing those particles, either by its weight or by its elasticity; so that, as a matter of fact, the pressure upon the mercury of the barometer is increased by the presence of atmospheric vapour. If there were no counterbalancing agency at work, the barometer would stand higher in moist air than in dry, and the south-west wind would tend to raise the column of mercury by the weight of the vapour-load which it brings. But the air in the case of this wind is, it must be borne in mind, expanded and light, in virtue of its high temperature, and this lightness of the air more than counteracts the additional pressure of the vapour. Of the two combined influences, the levity of the air acts more effectively than the heaviness of the vapour; and the preponderant result is, therefore, a diminution of pressure. The south-west wind causes the barometer to fall by its warmth, and as a consequence of the expansion and rarefaction which are the concomitants of the high temperature. But in all circumstances it is the movement of the barometer—its rise or its fall, and not the mere height or depression of the column of the mercury in reference to the fixed scale of the instrument—which is the mark of approaching change. This must be the case, since it is wind which is at the bottom of the affair. A very low barometer, if perfectly steady and without any tendency either to rise or fall, may exist for any length of time without the occurrence of rain. This is the case because, under such circumstances, there is the same low and steady atmospheric pressure for considerable distances in all directions, and there consequently can be no wind to bring in any sustained deposits of moisture. If there were wind, there would assuredly be a region of high pressure not far away from where the barometer is low. There must be a difference of pressure at short distances apart to set up an air-drift or current. The falling or rising barometer possesses its significance as a mark of changing weather because it is incident to the prevalence of wind. A falling barometer is of necessity connected with high atmospheric pressure and low atmospheric pressure existing at comparatively near stations. It may, for the most part, be taken as the sign at one fixed spot that higher and lower air-pressure are operating not far away. The fall is then due to the gradual drifting up of the lighter air, which acts with a low pressure, and the drifting away of the heavier air in the giddy whirl of some aërial conflict. An adequate and complete appreciation of the air movement in progress requires that the indications of the barometer at numerous stations around should be simultaneously known. The observation of the behaviour of a single barometer at one particular spot is only of practical moment as an approximate expedient, and because it enables a fairly probable guess to be made of the state of the air-pressure around. When the column of the mercury is stationary, it is inferred that there certainly can be no great difference of air-pressure near; if there were there would assuredly be wind moving over the place, and if there were wind the general mass of the heavier air would be drifting towards the position of lower pressure, or lighter air, and there would consequently be either a rising or

falling barometer, as the heavier or the lighter air came in over the instrument. A falling barometer thus shows that lighter air is approaching the station where it is observed; and as in the British Isles the lighter air almost invariably comes from the warm south-western sea, it brings with it clouds, and more or less copious deposits of rain.

A due regard to these considerations at once furnishes a ready illustration and proof of the insufficiency, and, indeed, utter absurdity of the old practice of marking the scales of barometers with words which were taken to imply the conditions of the weather that were to prevail when the top of the mercurial column ranged near their position. Thus the height 29·5, or 29½ inches, was assumed to be the midway line separating fair from foul, and accordingly was inscribed as "changeable," half an inch above it being marked "fair," and half an inch below "rain;" an inch and a half above changeable was regarded as "very dry," and an inch and a half below it "stormy." In this arbitrary and altogether unwarranted formula, in which a fixed standard was assumed for a condition of nature that is itself literally as unstable as the wind, it was in some general sense conceived that the instrument was only to be used in situations which were about at the same level as the surface of the sea. Of course it was well understood by the makers of the barometers, although, unfortunately, not as certainly by their purchasers and users, that one thousand feet of difference in elevation would at once shift "fair weather" into "rain." One thousand feet above the level of the sea corresponds with an inch less of pressure on the barometer. Therefore, with two barometers of altogether similar quality and construction, one placed at the level of the sea would declare "rain" as imminent; whilst the other, upon a hill-side one thousand feet above, but under otherwise precisely similar meteorological conditions of the air, would be uncompromisingly fixed at "fair." But there is a still more serious reproach than even this hanging over the old plan of scale-nomenclature. From the mere difference of atmospheric pressure at different times in the same place, in temperate regions of the earth, the column of the barometer varies in height in extreme cases between twenty-eight and thirty-one inches; and in frequently recurring instances between twenty-nine inches and thirty inches and a half. Now the "changeable" point may, in reality, correspond with any and every part of this extended range. A barometer which has been standing steadily for some days at thirty-one inches of the scale, if it fell to thirty inches within twenty-four hours, would give a most absolute indication of change, and intimate most certainly the approach of strong wind, and most probably also of rain, although at the lowest elevation it was corresponding with "fair" upon the scale. And so, in a similar way, a barometer that had been standing at twenty-eight inches for some days, if it rose within twenty-four hours to twenty-nine inches, would assuredly indicate that a cold dry wind was at hand, although the word on the scale with which it was then associated would be "rain." A barometer standing steadily at "changeable," as a matter of fact gives a more trustworthy promise of a continuance of fine weather than one which is descending rapidly from "very dry" to "settled fair." There is nothing, therefore, to be done with these old arbitrary scale-nomenclatures but to reject them at once as unworthy of the attention of anyone who pretends to turn the barometer to a serviceable and scientific use. This is now well understood by all meteorologically instructed people; but it is, nevertheless, a point of such paramount importance to the application of the instrument to any purpose of prognostication or forecast, that it is not possible to do otherwise than insist upon it here, even at the risk of seeming to repeat what, in this age of improved scientific teaching, all educated people should be presumed to know.

The Meteorological Office of London, which is gradually organising itself into an important depository of meteorological information, adopts one inch and a half as the frequent and common, and three inches as the possible, range of barometric pressure for places situated like the British Isles. A former President of the Meteorological Society (Mr. H. S. Eaton), by an elaborate discussion of barometric records made in London during the last hundred years, has determined the mean height of the mercurial column for that period and place to have been 29·952 inches. The range of the barometer for the sea-level in London may therefore be taken to lie very nearly between 28½ and 31½ inches.

In proceeding now, after this preliminary clearing of the ground from erroneous conceptions and fallacies, to point out what the real capacities of the barometer as a weather guide are, it may not be amiss as a first step to recall to the mind of the reader the circumstance that there are two great antagonistic currents affecting the atmosphere of the earth—the one flowing in general terms from

the poles to the equator, and the other from the equator to the poles. The polar currents—that is, the aërial streams *from the poles*—flow for the most part at a lower level near the surface of the earth, whilst the equatorial currents pass in the opposite direction above, so that between them there is a kind of vertical circulation of the air. Some such circulatory movement of course must be established, since the air which flows from the poles has to be continually fed by a compensatory current of supply. There is at no time any cessation of the flow; but the equator-ward advance of the lower currents of the air is, to a certain extent, biassed by the rotatory whirl of the earth. The air which comes from the parallels of narrower rotatory movement, hangs back over the terrestrial surface, which is advancing with a higher rate of speed towards the east. The currents which are flowing towards the pole, being impressed with the higher momental velocity of the wider terrestrial circles they are leaving, overshoot the actual eastward movement of the ground, and so give a westerly set to the southerly wind. This, it will be observed, is exactly the reverse of the trade-wind procedure already described.* The south-west wind, so prevalent in England, is primarily the reversed air-current which returns above the north-east trade, and which very commonly makes its way down to the lower levels of the atmosphere somewhere between the thirtieth and fiftieth parallels of north latitude, and then flows on along the immediate surface of the sea. The southing of this wind is its natural set from the equator to the pole, and its westing is the rotatory impulse impressed upon it from the whirling earth. In the lower latitudes, the general flow of these two antagonistic currents, the one above and the other below, is maintained with almost unswerving evenness and regularity; but in the higher latitudes, where what are termed the "variable winds" prevail, it is sometimes the one and sometimes the other of these currents which is in the ascendant at any particular station or spot, and then when the polar current is predominant the air of the place is cold, heavy, and dry, and when the equatorial current is in the ascendant the air is warm. light, and moist. With the former condition, as a matter of course, the high reading of the barometer accompanies the predominating influence of the heavier air; with the latter, the low barometer indicates the opposite condition of the atmosphere.

* "How the Wind Changes:" "Science for All," Vol. II., p 15.

A rapid fall or a rapid rise in the column of the barometer, from whatever point of the scale the fall or the rise may begin, intimates that a strong wind is about to blow, and that this wind will bring with it a change in the physical conditions of the air, or, in other words, of the weather; but of what precise nature that change is to be must in the main depend upon the direction from which the strong wind is about to arrive. As a general rule, in such circumstances the wind in England will come in from the south-west, and will be accompanied by rain, and the change will be experienced in the first instance towards the west, and will be gradually passed on towards the east. Wet weather very commonly indeed begins in Ireland a day or so before it is experienced in the neighbourhood of London. Actual storms are quite frequently felt upon the south coast of Ireland thirty-six hours before they present themselves in the estuary of the Thames. In such instances their approach is now invariably proclaimed beforehand in the precincts of the great metropolitan centre of commerce by the instrumentality of the electric telegraph. When the differences of the readings of the barometer at two remote stations within the extent of the British Islands can be telegraphically compared, it is possible to estimate with a fair approach towards certainty even what the strength will be with which the in-coming wind will be found to move. Thus it has been well ascertained that a strong, fresh gale scarcely ever prevails upon the southern coasts unless there has been a few hours before a difference of at least half an inch in the readings of the barometer in the north of Scotland and in the south of England. But if, with a south-west wind, the barometer in London falls half an inch in thirty-six hours, this is obviously pretty much the same thing as knowing that there was a difference of the same amount at places between which the general air-drift has moved within that time, since it is the drift of the wind which is the effective cause of the fall.

But yet again, when by the help of telegraphic information the readings of the barometer at several different stations around are known, it is quite possible by their comparison to discover beforehand what the direction is from which the approaching wind is on its way. Thus, assuming that at any particular instant it is found the barometer is standing half an inch lower at the northern extremity of Scotland than it does in London, the strong wind will almost certainly arrive from the west; but if the low reading is in London and

the high reading is in Scotland, the wind will come from the east. The spell by means of which this piece of meteorological necromancy is worked is the one which is technically formulated and known as "Buys Ballot's law,"* and which, it will be remembered, is to the effect that if an observer stands with his left hand towards the place where the barometer is low, and with his right hand towards the place where it is high, he will almost certainly have the wind blowing upon his back. Thus, with low pressure in the west and high pressure in the east, the wind will be from the south; but with the low pressure towards the east and the high pressure towards the west, the wind will be from the north.

The ordinary and proper course through which the variable winds change, or veer, in the northern hemisphere of the earth, is from west through north to east, and then from east through south to west.† When the wind veers in England, in this usual course, from the south-west through west to north, the barometer rises and the air-temperature falls during the progress of the change. In the season of summer the progress is accompanied by rain, and not infrequently by thunder-storms. In the spring it is often associated with sleet and snow. This is all due to the circumstance that during the change a strong conflict is taking place between the warm and moist equatorial current and the cold and dry antagonistic one from the pole. The thunder-storms are invariably the more violent accordingly as the difference of temperature is greater in the two contending currents. After this state of things has continued for some little time, the sky clears, and the barometer first ceases to rise, and then begins to fall with the wind from the east. High streaks of cloud next appear, drifting up from the south, and gradually thicken and descend until they cover the sky. With the first advent of the south wind below snow frequently falls, on account of the greater coldness of the place; but if the barometer continues to fall whilst the wind veers through south-east and south to south-west, the snow speedily gives place to rain. One of the most constant and trustworthy of the signs of the approach of a moist south-west wind is the appearance of clouds moving in that direction in the higher regions of the atmosphere, although the north or east wind may be still blowing below. If this occur with a falling barometer, there need be no doubt that the south-west wind will soon be established. The light south-west wind prevails at high elevations before it can make its way through the denser strata beneath; the north-west wind, on the other hand, more commonly affects the entire depth of the cloud-bearing layers of the atmosphere at once.

Violent gales most commonly burst upon the British Islands from the south-west, and are due to the sudden supremacy of the equatorial current after a conflict with the polar one. Storms from the north-east, however, occasionally occur, and when they do are especially dangerous; because they give less obvious indication beforehand of their approach, and also because they are more pertinacious and inveterate when they prevail, often blowing steadily from the same point, without any tendency to shift or veer, even for days. They are generally preceded by a prolonged continuance of low temperatures and cold weather.

When the wind veers through a retrograde course, instead of through the one that is generally pursued — that is, when it shifts from north-east through north and west to south-west, a process which is technically distinguished as the backing of the wind—this is usually associated with a continuance of coarse and unsettled weather. The disturbance in such case may be referred to the warm south-west current gradually forcing its way through the resistance of a strong polar wind.

The high steady barometer and calm settled weather are characteristic of the condition of the atmosphere which is meteorologically distinguished as the "anticyclone," and which has been already alluded to in this work.‡ In this state there is a general tendency in the air to move gently out from the position of highest atmospheric pressure all round, and to veer through the retrograde course —that is, from south through east to north. The case is, however, effectually distinguished from the retrograde veering above referred to as indicating unsettled weather by the gentleness of the breeze, and by the height and steadiness of the barometer. When the barometer continues steadily high at any given place, with a light wind and dry weather, there is, so to speak, a superabundance, or heaping up, of the air there, with no other tendency to movement than that which is connected with a gentle overflow in all directions around.

The conclusions drawn from the rise and fall of the barometer have frequently to be modified by the

* "How the Wind Changes:" "Science for All," Vol. II., p. 20.

† Ibid., Vol. II., p. 18.

‡ "Weather Telegraphy:" "Science for All," Vol. II. pp. 368, 370.

consideration of other meteorological conditions—such as temperature, moisture or dryness of the air, direction and force of the wind, and the general aspect of the sky. The temperature and moisture of the air are ascertained by the agency of instruments provided for that purpose, and known as the thermometer and hygrometer. Of these, the thermometer is even more sensitive than the barometer. A sudden rise of the air temperature in winter time is always an event of suspicious augury. It has been remarked that whenever there is a difference of something like thirty degrees in the temperature of the north of Scotland and the south of England, heavy gales are almost sure to ensue. The indications of approaching change furnished by the thermometer are, on the other hand, subject to the serious drawback that the instrument is simultaneously affected by various incidental causes of disturbance, such as exposure and position, and, above all things, the recurrence of alternating day and night. The changes of temperature due to these disturbing agencies are commonly so large in amount that they quite swallow up and destroy the influences incident to the movement of the wind, and therefore are only of secondary importance in comparison with the indications of the barometer. But they nevertheless have a certain practical value when properly and relatively regarded. Thus, if the air gets warmer and damper with a falling barometer, it may quite safely be inferred that a south-west wind is at hand; and if it becomes colder and drier with a rising barometer, there is the same certainty of assurance that a north-east wind will soon be in the ascendant. If the air gets warmer with a high barometer and a north-east wind, a south wind will not be long before it appears. If the air becomes colder with a low barometer and a south-west wind, squalls from the north-west will almost certainly follow, and if it be the season of winter, these will be most probably accompanied by snow.

It may, perhaps, be as well here to remark, although the circumstance must be pretty generally known, that the first indication of change in the height of the barometer after it has been stationary for some time may be found in the appearance assumed by the top of the column. It becomes concave when the mercury is about to fall, and convex when it is about to rise. The reason for this is, that either the ascent or descent of the liquid metal begins at the central part, where it is least influenced by adhesion to, or attraction by, the glass of the tube, and where it is, therefore, more free to move under the alteration of the pressure. This changing contour of the summit of the column is "mercurial" in more senses than one. It is perhaps the most delicate of the symbols which have to be interpreted by weather prophets, and before all else justifies the remark happily made elsewhere,* that meteorologists "feel the pulse of the atmosphere" when engaged about their forecasts. A steady barometer for the most part indicates that no change in the weather is at hand. A very slow rise from a low point is usually associated with high winds and dry weather. A very slow fall from a high point is usually connected with wet, unpleasant weather without much wind. There is, however, most danger of a sudden change occurring without clear barometric warning when the column is standing low, because heavier air of necessity always tends to force its way in when the pressure is low. It very frequently happens that several distinct areas of low pressure, such as are indicated by the low state of the barometer, follow each other across the Atlantic in rapid succession, like eddies pursuing each other in a turbulent stream of water. There are then successive bursts of storm, separated from each other by pauses of calm. A singularly marked illustration of this state occurred in the spring of 1868, when not less than twenty-seven distinct storms were recorded in the Meteorological Office between the 13th of January and the 25th of March.

* Scott: "The Barometer Manual of the Board of Trade."

A BAR OF IRON.

By George W. von Tunzelmann, B.Sc., etc.

A BAR of iron, as it usually appears to the eye, is brownish in colour. The brown is, however, not the pure metal, but a coating of rust, which we have seen* is simply ferric oxide, or the gas oxygen in union with the metal through its contact with the air, or with water which contains the former. The rust filed off and a fresh surface obtained, we see at once that iron is a whitish, bright metal. In its native state, how-

* "Science for All," Vol. II., pp. 41, 241.

ever, mixed as it almost invariably is with various impurities, it is singularly unlike the metal turned out of the smelter's furnace.

Iron exists in small quantities in the native state, chiefly in meteorites;* but it is mainly found in combination either with oxygen or sulphur. Iron pyrites ("the diamond" of slates) are formed of a compound of iron with sulphur; but though containing the metal in large quantity, they are not used for its extraction owing to the difficulty of completely removing the sulphur, a very small quantity of which is sufficient to render the iron useless. The ores from which iron is actually extracted contain the metal in combination with

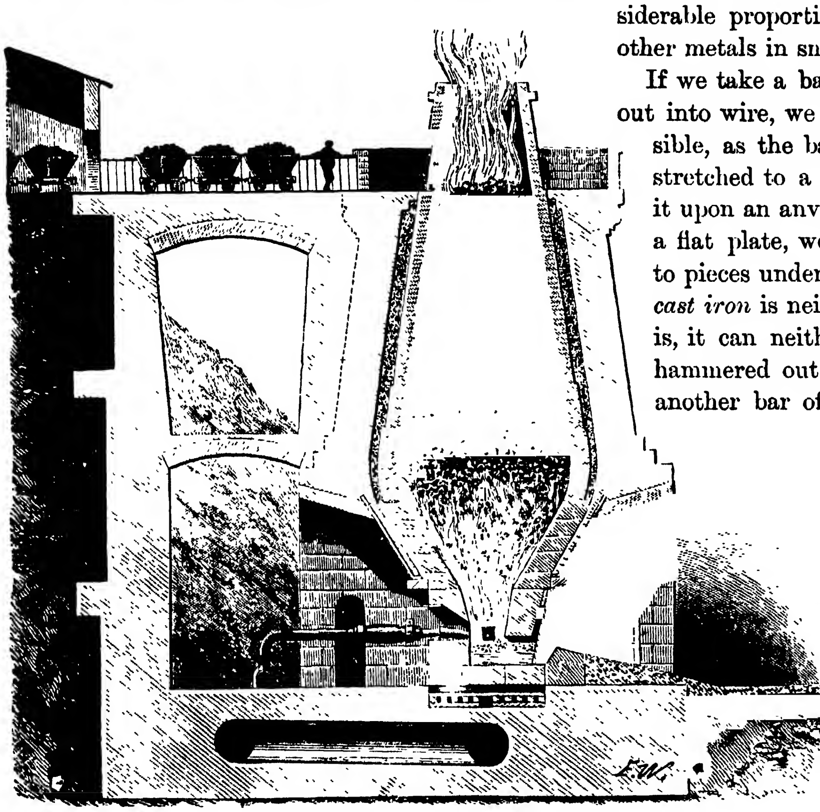


Fig 1.—Section of a Blast Furnace.

oxygen, and sometimes with carbonic acid, and the value of the ore depends far more upon the nature than upon the quantity of other substances present.

In the extraction of iron on the large scale, the process is usually begun by *roasting* the ore mixed with coal (or charcoal in countries where wood is plentiful), either in open heaps or kilns, in order to expel water, and also carbonic acid if present. The ore is then introduced alternately with layers of fuel and of limestone into a *blast furnace*, which is kept at a high temperature by a continuous blast of hot air (Fig. 1). The object of the limestone is to form a fusible slag, which surrounds the metal when first formed, and thus preserves it from being oxydised, and also prevents the formation of a less fusible slag containing iron, which would entail a large loss of metal. The iron gradually collects at the bottom of the furnace, and is run off from time to time by piercing, with an iron bar, a plug of sand and clay by which the tap-hole is closed. The iron so obtained is known as *cast iron*, and is combined with a large quantity of carbon obtained from the fuel, together with other impurities, such as silicon, sulphur, phosphorus, often a considerable proportion of manganese, and frequently other metals in smaller quantities.

If we take a bar of cast iron and try to draw it out into wire, we shall find that it will be impossible, as the bar will break before it has been stretched to a sensible degree. If now we lay it upon an anvil and try to hammer it out into a flat plate, we shall find that the bar will fly to pieces under the hammer. Thus we find that *cast iron* is neither *ductile* nor *malleable;* that is, it can neither be drawn out into wire nor hammered out into a sheet. We will now take another bar of cast iron, long and narrow, and we will try to bend it; but we shall find that this too will be impossible, as the bar will break off short even if the force be very gradually applied.

We will finally suppose that a short, thick bar of cast iron is placed between the plates of a very powerful press, such as a hydraulic press, and very great pressure applied. We shall find that in this way too it will be quite impossible to flatten out the metal to any perceptible extent, but when the pressure becomes very great the bar will be crushed. This last experiment will probably be beyond the means of most of us, but the others may all be performed with very little trouble.

We shall now describe an easy way of proving that *cast iron* cannot be stretched, as the apparatus is very simple, and will serve us again to show that *wrought iron* can be stretched. Moreover it will enable us to experiment upon the relative ductility of different metals in the form of wire or of narrow bars.

* "Science for All," Vol. IV., p. 33.

First we must procure from an ironmonger two pairs of pincers of a peculiar form, with the handles turned round into hooks, and known as wire-drawing *dogs* (Fig. 2). They are so made that when a loop of wire or stout cord is passed through the hooks at the end of the handles, and a small bar fixed at one end is grasped by them at the other, then the harder the loop is pulled the more firmly they grasp the bar.

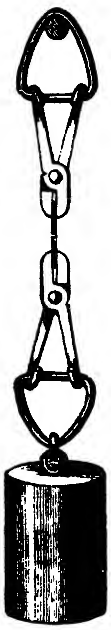


Fig. 2. Arrangement for Experiments on Ductility.

We now make a loop of very strong iron or steel wire, and pass it over a strong fixed horizontal bar, to serve as a support for the whole apparatus. On to the lower part of this loop we hook the first pair of *dogs*, and make them grasp one end of a narrow *cast-iron* bar; the other end of the bar must then be grasped by the second pair of *dogs*, from the handles of which a heavy weight is to be suspended by means of a second loop of strong iron or steel wire. Our apparatus is now complete, and we must go on increasing the weight until the bar breaks, which we shall find it will do quite suddenly, without previously stretching to any perceptible extent. In this experiment we should of course use as thin a bar as possible; but supposing we had apparatus at our command of sufficient size and strength to enable us to employ a bar having a section of one square inch in area, we should find that it would break off short when the suspended weight amounted to about eight or nine tons. This we express by saying that the tensile strength of average cast iron is such as will bear the strain produced by a weight of from eight to nine tons per square inch. If we were to take a short piece of a similar bar, having also a section of one square inch in area, we should find that it would not be crushed until the pressure amounted to about forty tons, so we see that average cast iron will bear a compressing force nearly as great as would be produced by a weight of forty tons per square inch. For example, a cast-iron plate ten inches square, and therefore containing a hundred square inches, would bear a weight of nearly four thousand tons without being crushed.

Owing to its brittleness, cast iron cannot be employed where it would be liable to sudden shocks, as in a railway bridge. It is found that the brittleness which we have shown to be characteristic of cast iron is due almost entirely to the presence of the large amount of carbon in combination with the iron, so that in order to get iron that will admit of being drawn into wire, or hammered out into sheets, we must remove the greater part of the carbon.

Iron which contains less than five parts of carbon in a thousand of iron is called *wrought iron*, and is then both malleable and ductile, the malleability and ductility gradually increasing as the proportion of carbon diminishes, while at the same time the temperature required to fuse the metal gradually rises. In order to obtain wrought iron from cast iron, the cast iron is melted in a shallow furnace, so constructed that the flames play directly upon the metal. Air is kept continually passing over the molten iron, and this causes a surface oxidation of the carbon and silicon, and also of a portion of the iron. The whole mass is constantly stirred with a long iron rod, in order to expose a fresh surface to the oxydising action, and also to mix up the oxide of iron formed at the surface with the melted mass, the effect of this being that the oxide is reduced to the metallic state by its oxygen combining with the carbon of the cast iron to form carbonic acid, while a siliceous slag is gradually formed upon the surface. The mass gradually gets thicker and more tenacious as the carbon is burnt away. Towards the end of the operation air is excluded from the furnace, and the mass is heated by itself for some time; finally it is drawn out in the form of a large ball of soft iron adhering to the end of the iron stirring-rod. This process is known as *puddling* (Fig. 3). As soon as the mass is removed from the furnace it is brought under a powerful hammer, to beat out the slag, and unite the particles of iron into a uniformly coherent mass.

If we take a bar of the wrought iron so obtained, and submit it to the same experiments that we made with the bar of cast iron, we shall find that its properties are very different. In the first place we shall find that when a pulling force is applied to it, it never breaks off short, as is the case with cast iron, but it first stretches to a considerable extent. We cannot draw out a bar or a short piece of thick wire into a long piece of fine wire by merely pulling the ends apart, for we can never get a bar that is perfectly homogeneous; there will always be some part that is weaker than the rest, so that the greatest stretching will take place at this point. Now as the stretching is greatest, the section will have become smallest at this point,

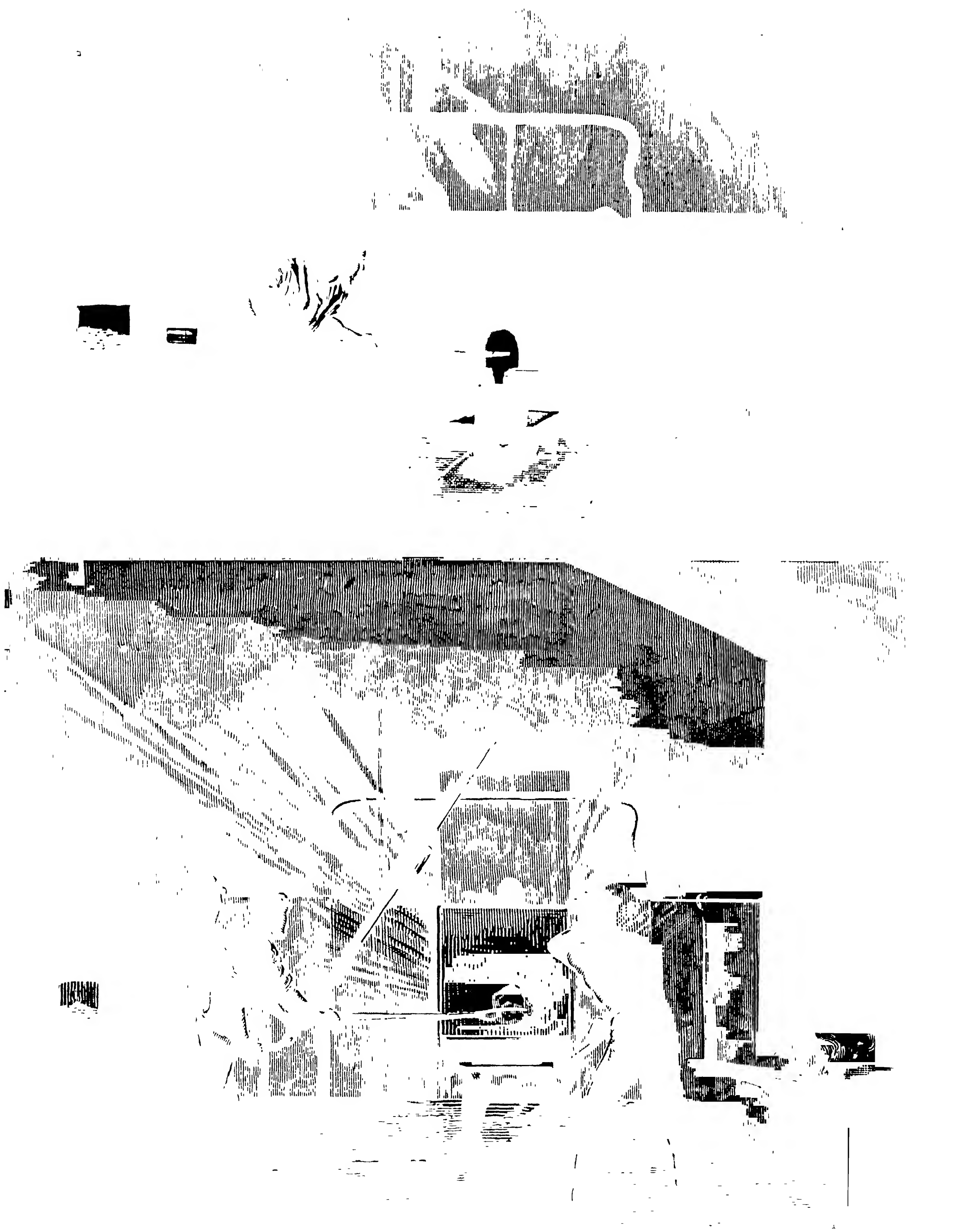


Fig. 3.—Puddlers at Work.
(*From "Great Industries of Great Britain."*)

and therefore as we continue the pulling there will be less resistance offered to stretching here than at any other part of the bar, so that we shall ultimately separate the bar into two pieces, each tapering to a point. In order to make the stretching even throughout, and so draw out a short round bar into a long piece of fine wire, we file down the end of it so as to make it fit into a hole, very little smaller in diameter than the bar, made in a strong steel plate. The bar is then pulled through the hole, becoming narrower, and at the same time longer; and this process is continued, using a smaller hole each time, until we have got a piece of wire as fine as we desire.

Iron is one of the most ductile metals, but even in its purest form its ductility is less than that of gold, silver, or platinum; but it is more ductile than copper. It is generally found that the properties of malleability and ductility go together, so that if we were to draw up two lists of metals, one arranged in order of ductility and the other in order of malleability, the two lists would be very nearly identical, but not precisely; for instance, we should find that in the first list iron would stand above copper, but in the second iron would be placed below copper, being less malleable, although more ductile.

Gold possesses both these properties to a much higher degree than any other metal, and indeed than any other known substance. This metal can be hammered out into leaves which are less than the 200,000th of an inch in thickness, and these leaves are transparent to the green rays, so that if a piece of gold leaf be held up between the eye and sunlight it will appear to be of a green colour. A single grain of gold may be drawn out into a wire 500 feet in length; but the best way of showing the extreme ductility of gold is to gild a bar of silver and then draw the bar into wire. One ounce of silver gilt with eight grains of gold has been drawn out into a wire 13,000 feet long, remaining throughout its whole length completely covered with gold. Ductility and malleability are chiefly illustrated by the metals, and in the middle ages they were supposed to be essential properties of a metal, so that the brittle metals, antimony, bismuth, and zinc, were called by the alchemists bastard or semi-metals: that is, as Paracelsus tells us, substances which are malleable to a certain extent, and which therefore somewhat resemble metals.

A good illustration of ductility is also afforded by glass, which is composed of a mixture of silicates of different metals, chiefly potassium, sodium, and calcium. Glass, though so brittle at ordinary temperatures, becomes extremely plastic and ductile when heated, and so great is its ductility that a glass tube may be drawn out at a moderately high temperature, and that without the aid of any apparatus such as a wire-drawing plate, into a fibre finer than a single thread of unspun silk; and if this fibre be examined by the aid of a microscope, it will be found still to retain its original tubular form.

Let us now try the effect of hammering a bar of wrought iron upon an anvil, and of compressing another bar in a powerful press: we shall find in both cases that the iron will flatten out to a considerable extent before it begins to crack. We shall also find that a bar of wrought iron may be bent without difficulty.

We shall find that the bar may be hammered out or compressed to a much greater extent if it be first heated to a strong red heat, as it then becomes plastic, and in this condition it can not only be beaten out very readily, but two separate pieces of metal can be hammered into one mass in such a way that no join is perceptible. This process, which is known as *welding*, will afford us a good illustration of the physical phenomena of *adhesion* and *cohesion*.

Adhesion may be defined as the physical force in virtue of which one body remains attached to the surface of another when the two bodies are brought into contact. *Cohesion* we define to be the mutual attraction which the particles of the same body exert upon one another.

We see from these definitions that there is not any fundamental difference between the forces of adhesion and cohesion, and the process of welding forcibly illustrates the imperceptible manner in which the former may pass into the latter, for when the two masses of iron first came into contact they would *adhere* to one another; but when finally welded into one mass we should speak of its different parts as being kept together by the force of *cohesion*.

The reader may try an experiment in illustration of this even more easily than by paying a visit to the nearest blacksmith's shop. Take two lumps of wet clay and bring them lightly into contact; they will *adhere*, but on being pulled apart the two original pieces will separate as before; now press the two lumps forcibly together, and we shall find, on attempting to separate them, that the two lumps of clay have now become one mass, held

together by the *cohesion* of its particles, and though we may divide this mass again into two or more parts by overcoming the cohesive force, we shall not be able to distinguish the two original lumps. We all know that if we dip our finger into water it will become wet, that is, a film of the liquid will adhere to it; but if instead of water we try the same experiment with mercury, we shall find that our finger will not be wetted. The reason of this is that the cohesive force, which keeps the particles of water together, is weaker than the adhesive force between the finger and the water, while in the case of the mercury, the cohesive force is stronger than the adhesive.

It is the adhesion of liquid films to the surfaces of solid bodies that causes what is known as capillary action.* This adhesive force of a liquid may overcome the cohesion of the solid, so that it dissolves in the liquid, forming a solution from which it can be again obtained in the solid form by evaporating the liquid.

If a solid be dissolved in a liquid, and we find that we cannot recover it unchanged by evaporating the liquid, then we know that besides the adhesion between the liquid and the solid there has been another force at work, a force known as chemical affinity.

The well-known fact that a clean needle will float upon the surface of still water is due to the adhesion of a film of air to the needle, which therefore floats upon a cushion of air.

When wrought iron is submitted either to a pull or to a pressure, we have seen that it gives way gradually. Now with average wrought iron it is found that if the weight causing this pull or pressure does not exceed about twenty-three tons per square inch of section, then when the weight is removed the iron will return to its original state; but if a greater weight be applied the iron will not resume its original shape, but will be permanently deformed. This we express by saying that the limit of elasticity of wrought iron is about twenty-three tons to the square inch.

In the process of removing the carbon from cast iron we have seen that the metal, which at the beginning of the operation is in a fluid state, gradually passes into the solid condition in a continuous manner, that is, without any abrupt change, so that we cannot fix upon any one moment during the operation and say that at that moment the iron ceases to be a fluid and becomes a solid.

* "Science for All," Vol. III., p. 63.

If instead of liquid iron we were to take some water, we should not be able to discern any such intermediate condition between the liquid water and the solid ice.

A substance which, like the iron, during a great part of the puddling process is not a solid and yet is not completely liquid, is termed a *viscous fluid.*

We may obtain a viscous fluid of any desired degree of viscosity by mixing bees-wax and oil in different proportions. In order that we may have a definite conception of what is meant by viscosity, we must first have an accurate definition of what is meant by a fluid. We may define a fluid as a substance which can support a stress or force only when uniform in all directions, except when the different parts of the fluid are moving unequally. Now, if we fix our attention upon any small portion, we see that it must be changing its shape, as otherwise there could not be any inequality in the motions of different parts of the fluid.

The capacity which a fluid has of bearing an inequality of stress while such changes are going on, is called *viscosity.* Accurately speaking, all fluids are more or less viscous, but unless a fluid be capable of supporting unequal stress for a perceptible time it is not called a viscous fluid.

This will be most easily explained by means of an illustration. Let us take a hard block of asphalte, which at first sight we should certainly call a solid, for it is quite hard, and so brittle as to fly into pieces on being struck with a hammer. If, however, we place the block in a large shallow trough and leave it long enough, we shall find that the slight inequality of stress due to the weight of the upper portions pressing upon the lower will cause it to flow in all directions, until it has covered the bottom of the trough to a uniform depth, and thus we see that asphalte is not a solid, but a viscous fluid. Next, let us repeat the experiment with some treacle by suddenly inverting a large vessel filled with that substance over the middle of the trough. We shall find that after a short time, but not immediately, the treacle will attain a level surface.

Finally, let us replace the treacle by a jar of water. We shall then find that, not taking account of the waves produced, the water will attain a level surface instantaneously, as far as we can judge.

The conclusions which we should draw from these experiments would be that asphalte is not a solid, as it would appear at first sight, but an extremely viscous fluid; that treacle is a viscous fluid, but that its viscosity is very much less than that of

asphalte; and finally that water is a non-viscous fluid.

Bar iron, properly hammered and rolled, is of a grey colour, and has a fibrous texture, but when the amount of carbon attains a proportion of about five parts in a thousand, its structure becomes granular or crystalline, and at the same time it acquires a dead-silvery lustre.

The hardness of iron increases with the amount of carbon, until when the proportion reaches about six parts in a thousand it becomes steel. Like wrought iron, steel was in early times made directly from the ore, and afterwards, and down to the present time, by adding the requisite amount of carbon to wrought iron by means of a process known as *cementation.*

Within the last twenty-five years several methods have been devised of making steel directly from cast iron, but the best kind of steel, especially that used for fine cutlery, is still prepared by cementation. In the manufacture of steel by the cementation process, a number of wrought iron bars are packed in powdered charcoal in fire-brick boxes, and kept at a full red heat for about from seven to ten days, according to the purpose for which the steel is required. In 1856* Mr.—now Sir Henry—Bessemer communicated to the British Association a method which he had discovered for manufacturing steel directly from cast iron. The Bessemer process consists in blowing a powerful blast of air through the liquid cast iron. Intense heat is evolved by the oxidation of the silicon, carbon, and manganese contained in the iron, and this heat is found to be sufficient to keep the metal in a liquid state during the process.

The first experiments were not very successful, as it was found impossible to remove the sulphur and phosphorus contained in the ordinary impure cast iron, and the first success was obtained with Swedish iron, obtained from the ore by means of a furnace fed with charcoal, and free from these deleterious impurities. It was afterwards found that the iron obtained from some of the English ores could also be used, and enormous quantities of steel are now made in England by this process.

Another difficulty was that it was found to be impracticable to stop the operation at the exact moment at which the proper stage of decarburisation was reached, so that a mass of pasty wrought iron was obtained instead of liquid steel. This difficulty was obviated by Mr. Mushet, a Scottish ironmaster, who suggested that the process should be carried to the point of complete decarburisation, and that a sufficient quantity of "spiegel-eisen" (a name adopted from the German for a white cast iron containing manganese and a large quantity of carbon) should then be added to convert the wrought iron so obtained into steel.

The operation is carried out in an egg-shaped vessel called a converter, made of wrought iron plates, and lined with a paste made by grinding up a very infusible siliceous rock known as gannister.

During the first part of the "blow," as it is called, the uncombined carbon of the cast iron enters into combination with the iron, and at the same time a siliceous slag, partly derived from the gannister, is formed. A yellow flame, edged with blue, now appears at the mouth of the converter, and the mass looks as if it were boiling, owing to the escape of the carbonic acid formed by the oxidation of the carbon. During this period the flames become more luminous and begin to flicker, while particles of slag and liquid iron are ejected from the converter together with showers of sparks, due to the combustion of some of the iron. In a few minutes the escape of gas diminishes, the shower of sparks ceases, and then the flame suddenly disappears. The blast is now stopped, and the fluid spiegel-eisen introduced, after which the blast is turned on again for a few seconds, and finally the steel is poured out into a ladle, and then into a series of moulds.

It is extremely important to stop the blast at exactly the right moment, as if stopped a few seconds too late or too soon the steel obtained is inferior in quality. Sir Henry Roscoe first suggested in 1863 that the spectroscope should be employed to determine the exact moment. It is found that this can be most easily determined by the disappearance from the spectrum of the flame† of some absorption-bands due to the presence of manganese, which disappears from the molten metal simultaneously with carbon. In 1878 Messrs. Thomas and Gilchrist showed that phosphorus may be eliminated in the Bessemer process by lining the converter with lime instead of with gannister, or even by simply adding lime to the contents of the converter. By the utilisation of this discovery, the Bessemer process has been successfully applied both in England and Germany to the manufacture of wrought iron and steel from very inferior qualities of cast iron.

* In Cassell's "Great Industries of Great Britain," the industrial relations of iron are discussed so fully that I have only touched on these, so far as they illustrate physical questions.

† "Science for All," Vol. II., p. 125.

The most remarkable property of steel is the extreme hardness which it assumes when suddenly cooled from a high temperature, which may be most conveniently effected by plunging it into water.

This treatment, besides hardening the steel, renders it extremely brittle and elastic. These effects may be partially removed by heating this "icebrook steel" to a moderate temperature, and allowing it to cool gradually, a process known as tempering. The higher the temperature employed for tempering, the softer is the steel rendered.

The workman judges as to the required temperature by observing the colours assumed by the surface of the metal during the process. These hues are the colours of thin plates,* due to the various thicknesses of oxide formed upon the surface. The hardest temper, used for razors and surgical instruments, requires a temperature of about 446° Fahr., and the tint is a light straw-colour. The lowest temper, which is employed for large saws and for chisels, demands a temperature of about 572° Fahr., and the colour is a dark-blue.

A SEED.

By Dr. Robert Brown, F.L.S., etc.

We have seen that the fruit is simply the ripened ovary or seed-vessel, and that its main purpose in the economy of the plant is to protect the seeds within its cavity, these seeds being again merely the ovules in a more mature stage. In brief, the perfection of the seed is the aim and sole end of plant existence, for inside the seed is the young plant which is destined to multiply and continue the pregeny, the propagation of the species being the ultimate purpose of vegetative life. In due time, the seeds being ripe, they must escape into the soil. To secure this all-important end, various means are adopted. In some fruits, like the pear, peach, and orange, and in the various grasses, including all cereal grains, the fruit does not open, but falls, and duly rots, and thus permits the seed to find its way into the soil, and to sprout when once it is there. In others, the fruit does not fall until long after the seeds have escaped. Here another series of contrivances comes into play. Either—as, for example, in the Indian cress—the fruit breaks into pieces, each piece containing a seed, or it opens by a special arrangement to admit of the ripe seeds falling to the ground. Not to occupy space with a description of the endless modifications which are found in different species and orders, we may call attention to a few of these simply as samples of the whole. In the poppy, the seeds are liberated through holes or pores, which open near the upper end of the fruit when it is ripe. In the iris and tulip the seed-vessel opens, as it were, by valves, and in the rib-grass, pimpernel, hibiscus, henbane (Fig. 1), the summit of the fruit lifts up, owing to its constriction, in the form of a cap. Other plants scatter their seeds at the moment of liberation, as in the crane's-bills (Fig. 2) and the squirting cucumber, which is so called from the habit of the fruit expelling its seeds with considerable vigour through one of the fruits or gourds. In the sandbox tree of the Isthmus of Panama (Fig. 3), the carpels or divisions of the fruit separate when it is ripe, and open, each into two valves, with such force and noise that it has been likened to an explosion. Accordingly, in collections, the fruits of this plant, in order to prevent them from flying in pieces, are generally firmly tied round with string, or even with strong wire.

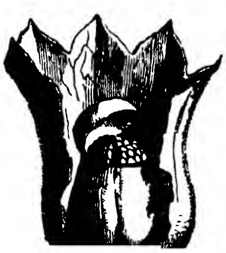


Fig. 1.—Fruit of the Henbane, showing the Lid which is raised to admit of the escape of the Ripe Seeds.

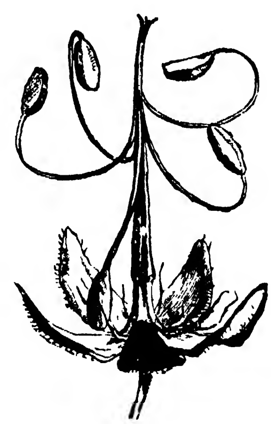


Fig. 2.—Fruit of a Geranium (Herb Robert), showing the method in which, by the elasticity of the Fruit valves, the Seeds are scattered.

But though these modes of freeing the seed from the vessel in which it has been confined may enable it to reach the medium in which it must sprout, and the young plant eventually to root, yet at most they will not send the seeds more than a few feet from the place where the mother

* "Science for All," Vol. III., p. 64.

plants grew. It therefore follows that all these elaborate arrangements for the plant's preservation will be in vain if the seeds of even one season were all to find resting-places in the immediate vicinity of the plant which produced them. Either they would not find soil enough to

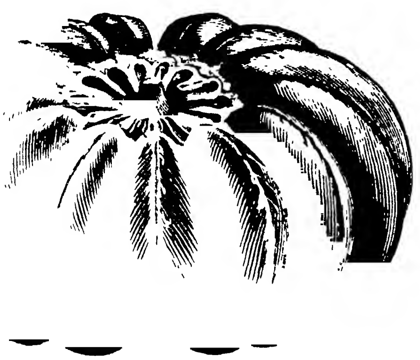


Fig. 3.—Fruit of Sandbox Tree (*Hura crepitans*).

support their life, or the majority of the plants would be choked by the more vigorous ones, and then succumb in the struggle for existence. Hence, some means must be taken to remove a portion at least of the seeds to a distance, in order that they may become colonists in a soil where they will have better means of bringing forth the young plants, of which they are the initiatory stages. And here we must again remind the reader that no plant, no matter how few or how many its seeds, ever brings them all to perfection, and that still less does every seed produce a plant. In the manner already indicated, a great number perish prematurely, otherwise the earth would speedily get covered with some prolific species of plants. We have also seen* how rivers, the winds, the sea, and other agencies waft seeds to soils, congenial or uncongenial, far off from the parent plant, and how wild animals, and even man himself, aid in the same necessary means for the preservation and prosperity of the species.

On many seeds there are appendages in the shape of hooks, wings, &c., which would appear superfluous were it not that they seem intended for the greater salvation of the plant by enabling it to disperse its seeds far abroad. A very common European species of burdock, *Xanthium spinosum*, has rapidly spread over South Africa and Australia by its seeds being carried in the fleeces of sheep. Many similar instances of plants with rough or hooked seeds being dispersed in an allied manner might be quoted. In the order of plants to which the dandelion and thistle belong, the seeds, or fruits, rather, are provided with a "pappus," or downy aigrette, which aids in wafting them to a distance, though it ought to be noted that this wing is not quite so valuable as it is sometimes represented to be, since it generally falls off at an early stage of the fruit's existence. In the same way the wing on the seeds of pine, firs, and their allies (Fig. 4), will assist them in their aërial travels in search of a new home, and thus aid in the formation of those vast forests of Coniferæ which cover so much of the Northern Hemisphere. We also find winged fruits in the common dock and parsnip, while in the mullein it is the pod that is winged, and in *Entada*, a gigantic bean of the West Indies, sometimes carried to our shores, and even to those of Iceland and Spitzbergen in the Gulf Stream, the pod breaks into segments, each of which is winged, while in the lime the bract may possibly perform the same purpose for the fruit. In the sharp-pointed corn salad (*Valerianella auricula*) the fruit is divided into three compartments, only one of which contains a seed. But as the other two cells are larger than the one holding the single seed, it has been suggested, and not unreasonably, that they enable the fruit to be wafted to a distance more easily than if the plant had produced more seeds, and in this manner provided for its preservation.

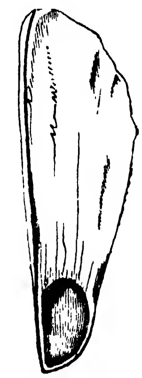


Fig. 4.—Winged Seed of Pine.

A species of grass (*Spinifex squarrosus*) found in Australia rolls itself into a ball, and is driven by the wind for miles over the parched sands until it comes to a damp place, when it expands and soon strikes root, while much the same arrangement for the diffusion of its species is seen in the "rose of Jericho" (*Anastatica hierochuntica*), a small annual which grows in sandy places in Egypt, Syria, and Arabia, and whose curious capacity for imbibing water and swelling up, has long been a familiar show in pseudo-scientific circles. But these modes of scattering the progeny of plants abroad have only a remote connection with the fruit or the seed. The fruits furnished with hooked coverings are most closely identified with the subject in hand. The burdock, the agrimony, the bur parsley, the enchanter's night-shade, the goose grass (cleavers, or Robin-run-the-hedge), and some of the forget-me-nots, are among this class. The

* "How Plants were Distributed over the Earth:" "Science for All," Vol. V., pp. 1—8.

hooks on the skin of these fruits are so placed as to catch in the hides of animals passing through thickets, thus enabling the fruit with the seeds inside it to be carried to a great distance from the plant on which it matured. In *Martynia*, a native of Louisiana, and *Harpagophyton*, a South African genus, the hooks are of so formidable a size that if once they become fixed into the skins of animals, it is difficult to extract them. It is said that if a lion gets unconsciously entangled in the fruit claws of the last-named plant the animal suffers great pain, and will roll about in the sand, trying in vain to get clear of them. Sometimes the hooked fruits get into the mouth of the king of beasts, causing serious inflammation, and in the end not unfrequently his death. In other plants, the fruits are sticky, and thus by clinging to the coats of animals, are eventually scattered broadcast, though naturally this can only happen in cases where animals are numerous in the districts where they grow. In the South American *Myzodendron*, the seed is furnished with two long flexible appendages. These catch the wind, and thus carry the seed from one tree to another. As soon as it touches the bough, the arms twist round the stem, and thus anchor the seed in the situation where, like the mistletoe, it is intended to root and become parasitic. In the underground clover (*Trifolium subterraneum*), as well as in a Brazilian species of bitter-cress (*Cardamine*), the ordinary ground-nut, and other plants in which the fruit ripens under the surface, there are ingenious arrangements for pushing it into the soil; and in the South American grass (*Stipa pennata*), the posterior end of the seed is prolonged into a fine corkscrew-like rod, which is followed by a plain cylindrical portion, attached at an angle to the corkscrew, and ending in a long and beautiful feather, the whole appendage being more than a foot in length.

The feather, no doubt, facilitates the dispersion of the seed by the wind. Eventually, however, it sinks to the ground, which it tends to reach—the seed being the heaviest portion—point downward. In this position the seed remains so long as it is dry, but if a shower comes on, or if dew falls, the spiral unwinds; and if, as is most probable, the surrounding herbage or any other obstacle prevents the feather from rising, the seed itself is forced down, and so driven by degrees into the ground. Sir John Lubbock, whose interesting account of the contrivances seen in this and other seeds for the purposes of distributing and placing them in the soil we have quoted,* is of opinion that the form assumed by certain seeds and fruits may also assist in the preservation of the species. "The pods of lotus, for instance, quaintly resemble a bird's foot, even to the toes: whence the specific name of one species, *Ornithopodoides;* those of *Hippocrepis* remind one of a horse-shoe; those of *Trapa bicornis* have an absurd resemblance to the skeleton of a bull's head. These likenesses appear to be accidental, but there are some which probably are of use to the plant. For instance, there are two species of *Scorpiurus*, the pods of which lie on the ground, and so curiously resemble the one (*S. subvillosus*), a centipede, and the other (*S. vermiculata*), a worm or caterpillar, that it is almost impossible not to suppose that the likeness must be of some use to the plant. The pod of *Biserrula Pelecinus* also has a striking resemblance to a flattened centipede, while the seeds of *Abrus precatorius*, both in size and in their very striking colour, mimic a small beetle, *Artemis circumusta*." Some lupins have seeds much like spiders, and those of *Dimorphochlamys*, a gourd-like plant, mimic a piece of dry twig. The seeds of *Jatropha* are indeed so remarkably like beetles, that it is difficult to divest one of the impression that the resemblance is simply accidental. We see clearly the two elytra or wing-covers with the dividing-line between them, the abdomen peeping out between them, and the head and thorax represented by a small lobe, which nevertheless exercises no appreciable effect during germination. Now what advantage could such mimicry be to the plant? We have seen (Vol. II., p. 284) that some insects mimic the forms of others, in order the better to escape their enemies. In the case of seeds, if the theory of Lubbock is correct, the mimicry of various animate objects serves quite the contrary purpose; in other words, its object is to tempt birds to swallow them. This, we know, is often done by insect-eating birds, with the result that the seeds are dropped not only indigested, but actually in a condition better fitted for germination than before they passed through the alimentary cavity of the bird. On the other hand, it might be a protection to the plant to have its insect-like seeds left unswallowed by a graminivorous bird. It is also not impossible that much of the beautifully ornate sculpture and colouring we see on the seeds of many plants (Figs. 5, 6, 7) may serve some purpose in their economy, though as yet we know too little of the questions involved in this subject to even

* "Fortnightly Review," April, 1881, pp. 426–455.

hazard an opinion as to the use of these seeming superfluities, though such have been the rapid strides in the direction to which we are pointing, that possibly, more quickly even than we expect, some curious light may be shed on this subject, at present so obscure.

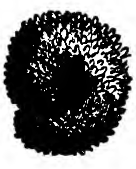


Fig. 5.—Seed of Chickweed.

What, in a few words, is the structure of an organ to the production, maturation, preservation, and distribution, of which so many elaborate arrangements are devoted? The seed we already know to be a fertilised ripened ovule, and though its general appearance and structure are, in some respects, the same as those of the ovule, yet, owing to its higher development and the changes produced in the progress of maturation, the adult ovule differs very considerably from the same organ which we knew at an earlier stage of the plant life, just as the fruit differed considerably from the ovary of which it is now the mature stage. Like the ovule, the seed is either stalked or stalkless, though in the latter case it detaches itself on arriving at maturity, from the little cord or funiculus, through which it is nourished in the early stages of its growth, the place of attachment being marked by a little scar to which, according to its position and shape, various very needless names have been applied. The seed is covered with two coats—an outer and inner one—the latter being the thinner of the two. To the former are often attached various appendages in the form of hairs, or other growths. For instance, the fibre we know as cotton, is the hair of the seeds of the cotton plant (Vol. I., p. 295), while in various species of Epilobium and Asclepias, the seeds are, as already indicated, furnished with a tuft or aigrette, which gives them a marked character. Sometimes, as in the seed coat of the *Camellia*, there is a dense coating of spiral vessels, from the arrangement of which M. le Monnier concludes that the seed coat is the representation of a complete leaflet. In other seeds, for example, in those of the passion-flower, there is a growth of a fleshy texture exterior to the coat; while in another form this growth constitutes, in the seed of the nutmeg, the orange-red, scented network so familiarly known as the spice called "mace."

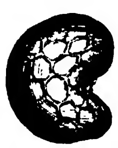


Fig. 6.—Seed of Poppy, showing Markings on the Coat.

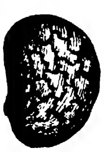


Fig. 7 riated Seed of the Tobacco Plant.

On cutting a seed open from above downward, and examining it with the microscope, or even with a magnifying-glass, or, in many cases, simply with the naked eye, we see that it is made up of the coats or integument mentioned, and that the kernel is the portion which the integument surrounds (Figs. 8, 9, 10). This kernel is usually composed of two parts, the embryo or young plant; and, surrounding the embryo, the endosperm, or starchy nutriment, on which it has to live during the progress of growth. Sometimes the latter substance is absent; but, as the embryo is destined to develop into a new individual, *it* must invariably be present in every fertilised seed. The origin of the embryo has been already sketched.* In some instances, the cellular tissue which forms the bulk of the kernel in the ovule is absorbed by the embryo in developing. In this case there is no endosperm—or albumen, as it is sometimes called—present in the adult seed, the embryo forming the sole constituent of the kernel. But in the majority of seeds it remains and increases, and taking a fleshy or horny consistence, forms round the embryo the cellular substance which is so familiar a constituent of (say) a grain of wheat. This endosperm is a cellular tissue without vessels, generally white in colour, and insipid to the taste. In wheat and other cereals it is farinaceous or mealy; that is, the cells of the tissue are filled up with starch grains, accompanied by gluten; in the seeds of—among many others—cocoa, poppies, and the castor-oil plant, it is oily; in the coca-nut it is fleshy, in the coffee-bean, date palm, and the plant in which it constitutes the "vegetable ivory" of commerce (*Phytelephas macrocarpa*), it is horny; while in the morning-glory and mallows it consists chiefly of mucilage, or vegetable jelly.

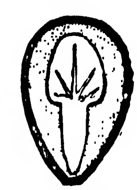


Fig. 8.—Section of a Seed of the common Wood Sorrel (Oxalis).

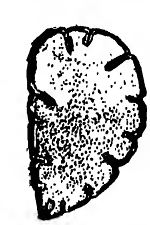


Fig. 9.—Section of Ivy Seed showing the Folds of the Coat penetrating the Endosperm, and also the Embryo at the bottom of the Seed.

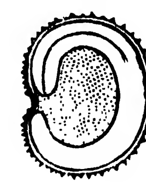


Fig. 10.—Section of the Seed of the Corn Cockle (*Lychnis Githago*), showing the Coat, the Endosperm, and the Embryo, which instead of being upright in the midst of it, is rolled round the Periphery of the Seed.

The *embryo* is the fleshy body in the seed which develops into the future plant. In reality, it is a perfect plant in miniature with lateral organs representing the first pair of leaves, or coty-

* "Flowering:" "Science for All," Vol. III., p. 41.

ledons, and an axis or stem, on the upper end of which is the tiny bud, which is destined to continue the upward growth of the plant; and at the inferior end, the radicle, in time to form the root through which the independent plant is nourished.* The embryo, however, differs in two great divisions of plants. Take a bean (Fig. 11) or an almond for example. After being soaked until it is soft, it is easy to strip off the integument of the seed; we then see that it is capable of being split into two divisions, between which is a little body. This

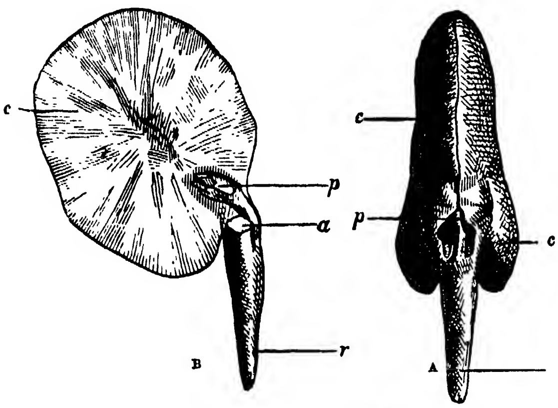


Fig. 11.—The Bean: A, Embryo with Seed-coat removed; B, Embryo minus one of the Cotyledons. r, Radicle; c, Cotyledon: a, Point of Separation of Cotyledon; p, Plumule.

tiny body is the embryo, or, at least, the stem and radicle of it, while the two lobes on either side are the cotyledons or leaves of the embryo swollen out to gigantic proportions by containing within them endosperm for the nutrition of the young plant, instead of this substance being around it, as we have seen is more commonly the case. But the great distinction in this class of seeds is that there are two cotyledons, or seed-leaves, in the embryo, and in the fact that there are two young leaves protruded above the soil when the young plant leaves the seed, and starts into an independent existence for itself. This fact is important, for it is one of the characteristics of that great group of plants distinguished by having their wood, when they have any, arranged in concentric circles, and the venation of their leaves netted. In brief, they are the division of *Dicotyledons*. In grasses, among other plants, the embryo has only one seed-leaf or cotyledon, and protrudes above the ground, at its first start out in life, only a single blade. Their leaf venation is also parallel, and their wood, as in the palms, is not arranged concentrically.† Hence, they are called *Monocotyledons*.

A seed attains its maximum size at an early stage of its growth. After this the kernel solidifies, without any further increase in size. Indeed, owing to the contraction of the exterior, the seed actually gets smaller as it gets riper. It also changes its colour in the progress of growth. At first it is like the rest of the plant, green, but as it ripens, the exterior gets paler, whitish, white, yellowish-brown, or black, owing to changes in the contents of the cells of the coat. Some seeds are diversified, and often brilliantly variegated with colour. Of this we have a familiar example in the different varieties of kidney beans.

Ripe seed is usually denser than unripe seed, to the extent that it will sink in water; hence the common test for it. The smaller density of unripe seed is owing to the imperfect, or entire want of, development of the embryo. Accordingly, it floats. This test is not, however, infallible, for some perfectly ripe and sound seeds will float likewise.

It is always of importance for the cultivator to know what value is to be attached to seeds, since they are so commonly adulterated with old ones which are utterly worthless. If, for example, he finds that only two-thirds of his seed will germinate, then he must sow a corresponding quantity over a given extent of ground. To test the germinating power, the following procedure, recommended by the eminent French agriculturist, Matthieu de Dombasle, may be useful, "Cover the bottom of a saucer or plate with two pieces of rather thick cloth which have been wetted, and place the one over the other. Spread on this a certain number of seed, taken at random from the package to be tested, each seed being separated by a small space from its neighbour. Then cover them with a third piece of cloth like the first two, and wet it. Now place the plate in some moderately warm place, such as on a chimney-piece, or in the vicinity of a stove. As the cloths begin to dry, wet them again, but allow no surplus water to accumulate about the seeds; and accordingly, after the cloths have absorbed all they can, pour off the surplus by raising gently the plate from the horizontal. The progress of germination can be watched day by day, by simply raising up the topmost piece of cloth. Those seeds which have lost the power of germinating will generally in a short time get covered with moulds."

In order that the young plant may burst the

* The nature of the endosperm, the position of the embryo in the seed, and a host of allied topics have given rise to a vast amount of technicalities, which have been studiously avoided in this brief sketch. The whole of these questions are discussed in my "Manual of Botany," pp. 495–543.

† "How Plants Grow:" "Science for All," Vol. I., p. 302.

envelope of the seed, and take the first steps to become the future plant—in short, that it may germinate—certain conditions are necessary. In the first place it must be deposited in the soil or other element in which it is intended that the plant should grow and extract its nutriment from. A certain degree of moisture, temperature, and oxygen is necessary to the successful accomplishment of this important process in the life of the plant, though, contrary to the usual belief, darkness is not essential to the germination of most plants. The time required for a plant germinating varies from a few hours to two years. The seed of the mangrove sprouts even before the fruit has fallen off the branches into the soft ooze beneath. The seeds of the willow will germinate a few hours after being sown; those of the walnut or pine in four or six weeks; while those of the rose, hawthorn, ash, dogwood, maple, and other trees, are said not to germinate until from one-and-a-half to two years after being put into the ground. The depth at which seeds should be sown varies according to the nature of the soil, the supply of air or warmth, the kind of weather, the degree of moisture, &c., all of which are so variable that it would be rash to lay down any rule of practice which should not be received with the latitude to which the circumstances mentioned entitle it.

The seed has germinated; it has absorbed water and burst its cerements; the embryo is stimulated into life and vigour: now how is it to be nourished and its growth kept up until it can extract its nutriment from the soil? At first the young plant lives entirely at the expense of the seed, feeding on the nutriment stored up in the endosperm, or if this is wanting, by the similar materials contained in its own cotyledons. This substance, starch, is not, however, soluble in water, and thus the nutrient material must be in a state of solution before it is fitted to nourish the embryo: hence starch must be transformed into some substance which is soluble in water. The process involved in the nutrition of the young plant, therefore, falls under three heads: (1) The solution of the nutritive materials of the cotyledon or of the endosperm; (2) their transfer to the embryo plant; (3) their assimilation or conversion into the substance out of which the plant is built up.

Without going into details, it may be stated in general terms that the main processes in the elaborate vital laboratory of the seed are, first, the absorption of oxygen, the result of which is the disengagement of carbon dioxide (carbonic acid gas), which causes that diminution in the weight of the seed well known to take place during germination. Next, starch is converted into dextrine, and that again into sugar. Thirdly, sugar is consumed and disappears, being converted into carbon dioxide. Last of all, the combination is accompanied by the disengagement of heat, a phenomenon well known to any one who has examined a heap of malt in the process of germination, for the mass of sprouting grain has to be continually turned over, in case the malt should be damaged by too much heat. The second stage in the nutrition of the young plant is the transfer of the nutriment to it. This is accomplished by the water which it absorbs entering the cells, dissolving out the dextrine and sugar there stored, and carrying them to the embryo. The place where it enters the embryo is at the point where the cotyledons join the stemlet (Fig. 11); and hence the nutritive materials are distributed at first chiefly downward into the extending rootlets, and after a little, downward and upward toward the extremities of the seedling. The third stage is the assimilation of the nutriment by the seedling. Here we have a process exactly the reverse of the first stage of nutrition, for instead of the nutritive matter being converted into *soluble* materials, they are transformed by the plant into insoluble substances such as the cellulose, of which its structure is built up. As to how this is accomplished we can at best only make a scientific guess. We see it done, but we cannot satisfactorily explain the intricately elaborate process. Possibly—and this speculation of Mr. Johnson is as reasonable as any other—the dextrine may be converted into cellulose, and the soluble albumenoids return to the insoluble condition in which they existed in the ripe seed.

These processes, however, at longest only last until the seed, having burst its cerements, the embryo, strengthened by the nutriment absorbed, begins an independent life for itself. The radicle or rootlet, as might be expected—is the first portion of the young plant which seeks the soil. It curves round, and finally, though cautiously, penetrates the element in which it is to root the plant, it may be for a thousand, or even, if we are to credit the estimated ages of the great Californian sequoias (*Wellingtonia*), several thousand years. Then the plumule raises itself into the light of day, and the ordinary growth of the plant goes on. But as Mr. Darwin has shown in an interesting work

abounding with curious observations on vegetable life,* the young root moves in slowly-described circuits, or "circumnutates," thus aiding insensibly in fixing the young plant in the soil.

And here the reader may ask, How long will seeds preserve their vitality? So many fables have been, and are still being, promulgated on this subject that a few facts may not be unacceptable. The seeds of the willow will not germinate after having been once dry, and their germinating power is lost in two weeks even if during that interval they have been kept fresh. The seeds of coffee and various other plants do not germinate after having been kept for any considerable length of time. The grains of wheat usually lose their power of growth after a lapse of seven years, though wheat over two centuries old has been found quite capable of being used for food. The stories of "mummy wheat" sprouting after having lain dormant in Egyptian tombs for thousands of years, are, to say the least of them, very dubious. No well-authenticated instance of such finds are extant, while among other articles sold by the Arabs to credulous travellers, as coming out of the same tomb as the ancient wheat, have been dahlia bulbs and maize, the deposition of which in the receptacle from which they were said to be extracted, necessitates the belief that 3,000 years ago the subjects of the Pharaohs were engaged in commerce with America.† Rye and wheat only 185 years old could not be induced to germinate, the place of the embryo being occupied by a slimy putrefying fluid. If, however, excluded from light and air, and, above all, from damp, seeds have been known to keep for somewhat lengthened periods. Seeds of the bean and pea order have sprouted after 100 years' storage in an herbarium, and many similar instances have been recorded. But few of them are beyond suspicion, there being invariably a doubt, either regarding the age of the seed, or about the fact of its having sprouted at all, when the date of its birth was well authenticated. For instance, the most profound suspicion attaches to the well-worn tale of the raspberry seeds found in a British tumulus in Devonshire, being contemporaneous with the coins of the Emperor Hadrian resting beside them, or to the instances of seeds of bird's-foot trefoil, and other plants found in Roman tombs of the second and third centuries, germinating. The seeds were doubtless discovered as described; but how long had they lain there? Seeds disinterred from the soil taken from under very ancient buildings and other situations have also sprouted, though the estimates of their age have been all the way from 500 to 2,000 years. They cannot, however, be considered beyond the range of scepticism. It is also a common matter of observation that no sooner is old ground trenched than plants appear which had never been observed in such spots previously, and that after fires pass over localities plants equally strange to the neighbourhood appear. For instance, it is noticed that when an American forest is fired, the trees that take the place of the burnt ones are of a different species to those hitherto observed in that neighbourhood; and after the Great Fire of London in 1666, the yellow rocket appeared for the first time in much profusion in the districts swept by the flames. These facts—and they are not to be denied—have suggested the theory that seeds may lie for long periods dormant in the soil, and only spring into life when some stimulus, such as exposure to the sun, rain, or heat is applied to them. Doubtless, seeds will preserve their vitality longer if kept from extremes of temperature than otherwise, and on this ground the tales told may not be without a certain substratum of truth.‡

The latest report of this description may be quoted as a specimen of many much less authenticated "facts," as well as for its own innate importance. It is to the effect that Professor von Heldreich, of Athens, discovered that an extensive tract of land, at the silver-mines of Laurium in Greece, is covered by a luxuriant crop of a horned poppy, belonging to a hitherto unknown species, which he proposes to designate as the *Glaucium Serpieri*. These plants have shot up through soil which has been covered to the depth of nearly ten feet with the masses of cinder and slag thrown out by the workmen in ancient times when the mines were worked by the Greeks, and which have recently been disturbed in order that the imperfectly fused materials might be subjected to a further process

* "The Movements of Plants" (1880), p. 69.

† So many of the Central African tribes, who have no tradition of intercourse with the whites, have been found cultivating maize that doubts may be expressed whether it is an exclusively American plant. But about the dahlia there can be no mistake: it is a native of Mexico, and was unknown to Europeans prior to the discovery of the New World.

‡ In my "Manual," pp. 522-5, a number of such data are recorded, and in Mr. R. W. Wright's "Life: its True Genesis," pp. 89—122, the subject is also discussed from the incredulous point of view—albeit the author is not among the men of little faith in other walks of hypothesis.

of fusion for the purpose of extracting their silver contents. If there is no mistake about the facts, the persistent vitality of the seeds through the interval of 1,500 or 2,000 years which has elapsed since the mines were last worked is certainly a curious fact in physiological botany, and is all the more interesting because this species of *Glaucium* is not known to exist in any other habitat.

One peculiarity of moderately old seeds is that they produce weak plants, a peculiarity which is taken advantage of by horticulturists to produce the varieties known as "florists' flowers." For instance, one-year-old seeds of the ten-week stock are said to yield single-flowered plants, while those which have been kept four years produce, for the most part, double flowers, which, from a botanical point of view, are monstrosities, the result of feebleness in the constitution of the plant. Two-year-old turnip seeds produce larger bulbs and less leaf than fresher seed, and the ordinary garden balsam also produces more flowers and less leaves if the seeds are kept some time than if sown the first year. Partially unripe seeds will also germinate, though, as a rule, they take longer in sprouting, and produce feebler plants than the fully matured seed. Light or dwarfed seeds sprout quicker but yield weaker plants, and in addition are not so sure of germination as heavy seeds, the number of roots and the strength of plants being in proportion to the amount of starch in the seeds from whence they have sprung. From observations made by Prof. Church it was found that the value of seed-wheat bears a certain relation to its specific gravity, and that (1) the seed-wheat of the greatest density produces the densest seed; (2) that the densest seed produces the greatest amount of dressed corn; (3) seed-wheat of medium density generally gives the largest number of ears, but the ears are poorer than those of the densest seed; while, again (4), seed-wheat of medium density generally produces the largest number of fruiting plants. Though I am not aware that the observations made by this eminent chemist have been repeated by any other observer, the care with which they were made precludes the likelihood of any error, and renders them of peculiar value to agriculturists. It has been discovered by M. Pauchon that black or violet seeds absorb more oxygen than white or yellow ones, though a more rapid germination is observed in the latter. On the other hand, the quantity of carbonic acid exhaled by white seed is found to be considerably greater than that exhaled by dark ones. The more frequent and pronounced pigmentation of seeds of northern lands may, therefore, be a favourable circumstance for the growth of these organisms, the conversion of the nutrient substances being more rapid, under the peculiar light conditions to which they are subject. Chlorine, bromine, and iodine stimulate the germination of seeds, and electricity has a remarkable effect on them, not only hastening the sprouting of the seeds, but the ripening of the fruit. But, like cold and drought, steeping seeds in the poison of venomous serpents does not check germination altogether. A certain amount of heat is, of course, absolutely necessary for the germination of seeds. But even an extreme of heat—especially if damp—is not unfavourable, but rather the reverse, to the early performance of the operation. Cereals immersed in sand and earth heated to 104° Fahr. sprouted, and the cocoa-nut is said to germinate in soil heated by the sun's rays to 81° Fahr. If, however, wheat, rye, and maize are unable to endure a prolonged temperature above 104°, it proves clearly how it is that many plants cannot be multiplied by seeds in hot countries, where the temperature of the soil is often as high as 140° Fahr. On the other hand, the seeds of many plants will endure great extremes of cold. For instance, those of many Arctic plants must be subjected during six months in the year to intense frost, though, at the same time, we must not forget that during the period of greatest frigidity they are covered by a deep blanket of snow. Some wheat which had been left by the U.S. *Polaris* Expedition in the upper reaches of Smith's Sound, was brought to England by Sir George Nares, and found to germinate freely, though during the interval it must have been exposed to a cold, on one occasion at least, over 105° below the freezing-point of water For in the spring of 1876 the thermometers recorded a temperature of 73° 75 below zero, and in all likelihood, it is often even colder in these hyperborean latitudes.

HIGH CLOUDS AND MOONSHINE.

By the late Robert James Mann, M.D., F.R.C.S., F.R.A.S., etc.

THE general aspect of the sky, and its cloud-physiognomy, are perhaps, after all, the most generally understood of the auxiliary characters that are drawn upon to give confirmation or point to the intimations of the barometer.* They are, indeed, unconsciously turned to good practical account by the most uninstructed and casual of observers. It has been long remarked that even the cloudless blue sky itself is not without a significance amidst the symbols of weather-prophecy. A bright and cheerful tint in the azure of the sky is a sign that fine weather is in the ascendant, whilst a dull and sombre blue prognosticates wind and an unsettled and capricious state of the atmosphere. The clearness of the air, which is familiarly recognised as the harbinger of rain, is very often due to the air having been freed from opaque and light-intercepting impurities as soon as insensible vapour begins to be deposited as actual moisture. All such extraneous particles become heavy as they grow damp, and in consequence they settle rapidly down towards the ground. The bright rosy sky at sunset, as has been already explained, is a characteristic of fine weather. The dull Indian-red or pale yellow sky at sunset is, on the other hand, the harbinger of rain. The copper-coloured, orange, or bright yellow tint are symbols of wind; and the lurid green hue in the west after sunset means rain as well as wind. The grey sunset is generally due to the presence of cirro-stratus clouds in the west in sufficient abundance to impede the free passage of the direct rays of the sun. The clearing of the sky at sunset after rain can by no means be accepted as a sure promise for the morrow, because in such circumstances the sky is very commonly found to be again covered with a heavy canopy of clouds on the following daybreak. The auspicious significance of the grey sky and the threatening augury of the red sky at dawn have already been alluded to. The rainbow in the morning is "the shepherd's warning," simply because it is formed opposite to the sun, which is rising in the east, and therefore shows that there are clouds gathering and rain falling towards the west, the direction from which wet weather most frequently comes. The rainbow at night is "the shepherd's delight," because it indicates that there are then clear air and unimpeded sunshine towards the west, and that the cloud-screen and rain are towards the east, and passing away. A high dawn—that is, the first break of daylight presenting itself high up in the sky, and above a well-marked bank of clouds—is correctly looked upon as foreshadowing wind. A low dawn, in which the first streaks of daybreak appear almost in contact with the horizon, is a significant promise of fine weather, because it tells that the sky is free from clouds. The appearance of dew in the evening is associated with fine weather, because it implies both a cloudless sky and a still atmosphere. Dew is the immediate result of the free radiation of heat into the unveiled air-spaces above, and it never, under any circumstances, begins with an overcast sky, or remains when there is brisk movement in the air.

The Rev. Clement Ley, who has been associated with the work of the Meteorological Office in London, directed attention to the importance of observing the movements of the upper clouds as indications of approaching change. The forms which he chiefly relies upon for this purpose are the mare's-tail and curl-cloud cirrus, which belong properly to an altitude varying from 25,000 to 40,000 feet above the sea level; the cirro-stratus, or high sheet-cloud, which is formed by the interlacing fibres of augmenting cirrus, and which is the cloud essentially concerned with the production of halos; and the small white flocculi, or cirro-cumuli cloudlets, which form also at a similar high elevation. Mr. Ley remarks that these clouds may commonly be seen crossing the direction of the lower air-drift by an angle of something like 55°, and from the side which is on the observer's left hand when he stands with his back to the lower wind. The course of these clouds almost always indicates the direction towards which the lower wind is about to veer, and they quite commonly present themselves as much as 100 miles in advance of the denser cloud-aggregation that is on the way behind. The barometer is usually high when these outlying streamers first appear; but it soon begins to fall, and the sky then becomes overcast with a veil of precipitating vapour, which thenceforth conceals the movements of the higher clouds, and gradually matures into rain. When

* "Weather Signs and Weather Changes:" "Science for All," Vol. V., p. 84.

the thickening bank of cirro-stratus first presents itself towards the south-east, and drifts from the south, this almost certainly implies that heavy rain is at hand. If, on the other hand, the first streaks of the gathering cirro-stratus present themselves towards the west, either no rain at all or only slight passing showers will be experienced.

The cloud-bank of approaching rain, as a rule, begins to form in the higher regions of the air, and gradually extends itself downwards to a lower level. When, on the other hand, loose streaks of cloud first appear against the blue sky in isolated spots, and at a comparatively low elevation, and are then gradually piled up into cumulus heaps above, with rounded protuberances that from time to time tumble back into the general mass, this may be regarded as a sign that, at the most, brief passing showers may occur. Mr. Ley especially insists upon the circumstance that whenever these, as it were, extemporised heap-clouds thus generated in the mid-spaces of the air connect themselves below with a broad stratified base, that indicates rain; whilst, on the other hand, when the tops of these cumuli spread out and blend into stratified cloud-masses above, whilst their bases diminish and melt away, the weather will certainly continue to be fine and dry (Fig. 1).

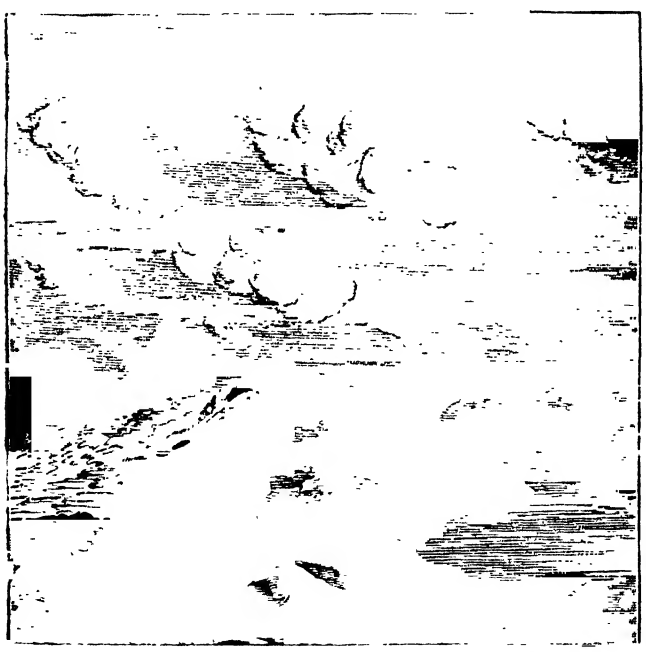


Fig. 1.—Mr. Clement Ley's Fine-weather Cloud, consisting of Stratified Beds resting upon the top of Piled-up Cumuli.

The peculiar form of cumulus which is associated with electric disturbance and thunder, and which has already been spoken of,* is, it will be observed, just the reverse of this fine weather type, as in it the cumuli rise out of a stratified base. During the prevalence of a high and steady barometer with a north-east wind in the summer season, when settled weather prevails, the sky is either cloudless, or small stratified clouds form at night at an elevation of a few hundred feet, and develop in the day into isolated masses of heap-cloud. In the winter season, on the other hand, the period of settled weather with a high, steady barometer is not uncommonly associated with a thin stratus-cloud spread over the sky for several days and nights continuously, or with only an occasional break. Whenever such openings do occur, it is at once seen that this cloud is limited to a comparatively low elevation, so that clear sky only appears in the higher regions of the air. The observer looks through a rent into cloudless space (Fig. 2).

Mr. Ley connects the formation of this durable fine-weather cloud with the prevalence at the time of a general downward movement of the air through a wide extent. In the summer this fine-weather deposit of vapour in a gently descending current of air is dissolved as rapidly as it is formed by the heat of the sun. But in winter, a thin level sheet of vapour is enduringly formed as soon as the descending current gets into a region of the atmosphere in which the air has been sensibly chilled by the effect of radiation from the solid surface of the earth. It is this condition of the atmosphere which is most liable to the production of fogs. The absence of horizontal movements in the air at such times favours their lingering and brooding over the place where they have been formed. The darkness of such fogs over large towns is very probably connected with the fact that the smoke, which is carried away and dissipated by an ascending current or horizontal wind, is driven back into the low misty canopy by the descending movement. Fogs of this kind only occur when the barometer is steady and high, and when the air temperature is at the same time low.

Amongst the long prevalent notions that have been held concerning the changes of the weather, there are, perhaps, none that have been more generally entertained and cherished than those which connect them with what are termed the changes, or, in other words, recurring phases of illumination of the moon. These notions, in all

* "Science for All," Vol. III., p. 39, Fig. 9.

probability, were in the first instance derived from the accidental coincidence of certain marked conditions of weather with particular aspects of the moon, and from the natural tendency which exists in the minds of superficially instructed people to ascribe to the heavenly bodies a power over human events. A very few words of comment will, nevertheless, suffice to expose the fallacy of this illusion. The proposition, however, to which these remarks are addressed, is, it must be remarked, not simply and in a general sense that the moon affects the weather experienced upon the earth, but that the mere aspects of the moon's varying illumination exert an especial influence upon the weather of each particular locality and spot.

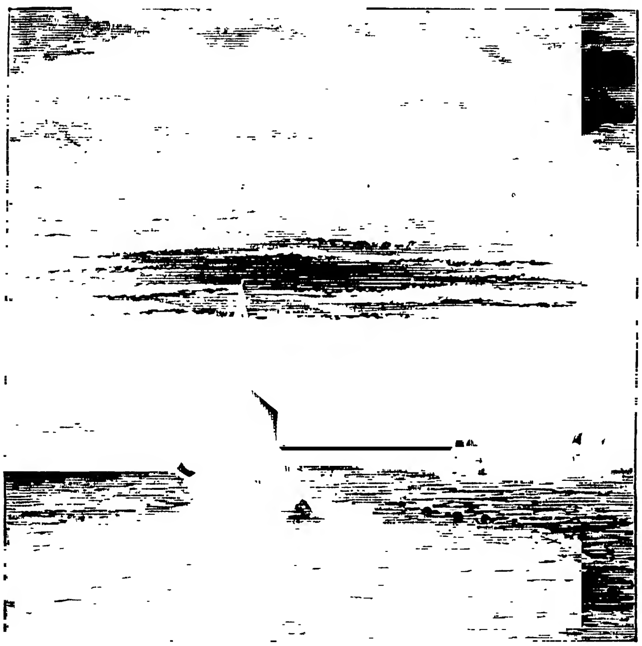


Fig. 2.—The Shallow Settled-weather Sheet-cloud of Winter, with the Clear Sky seen above through a Rent.

The utter irrationality and absurdity of this idea becomes apparent at a glance the instant it is connected with the obvious fact that the earth is a rotating and not a fixed globe. Assuming, for the mere purpose of illustration, that it were true the new moon, the half moon, and the full moon produced some especial state, whether of storm or of calm, whether of rain or of dryness, upon some given spot on the earth, as this passes round in front of the sun-illumined orb, it is manifest the same influence must continue to be exerted entirely round the earth during the subsequent twenty-five hours in which the terrestrial sphere whirls completely round before the moon. There would of necessity be a vast circular girdle or zone of the moon-generated weather, whatever that might be, impressed upon the earth. But it will be bootless to say that no such moon-generated weather-girdles are found upon the earth's sphere. In the terrestrial zone thus presented to the moon during each individual rotation of the earth there occur all conceivable diversities of physical state. Clouds and deluges of rain co-exist in one part with clear skies and genial sunshine, and bright starlight in other parts. The notion that one part in a zone of the whirling earth which comes in rapid succession under the moon can be differently affected from the rest of the zone is quite of the same order of intellectual apprehension as that which is involved in the occasionally expressed fear that a severe winter in England may imply that the earth has entered some colder region of space during its cosmical progress amidst the stars—a wild fancy, that is instantly dispelled when the simple question is asked, why the exceptional severity should not have been experienced over the whole earth, as well as in England? If the earth were thus transported into more frigid space, it would be colder everywhere, instead of colder at one part and warmer at another, as experience proves to be the case when there are severe winters anywhere. If the phases of the moon affected the weather, it is obvious that the same weather would prevail wherever analogous relations to the moon obtained.

The moon, as a matter of fact, does produce a physical influence upon the earth, but it is an influence of an altogether different kind to the one which is implied by this popular piece of weather-delusion; it is the influence which is so grandly expressed in the diurnal roll of the tides of the sea, and which is due to the inter-action of the lunar and terrestrial mass.* But this, it must be remembered, is an affair in which there is no room for the play of imagination or fancy. The rise and the recurrence of the tides are known beforehand, and even tabulated in the almanacks with the utmost exactness. Not only the time of high tide is marked for all the great port-establishments of the earth, but also the occasions when such rise of the tide will be exceptionally in excess or exceptionally in defect. But in this it is the moon which is operative in bringing about the result, and not the "phases" or appearance of the moon. The bulging water is drawn towards the moon, and follows it in

* "The Tides:" "Science for All," Vol. I., p. 204.

its circling course round the earth, without any regard to the phase which it may be presenting to the terrestrial observer's eye, or to the extent of the illumination at the time by the sunshine. The highest tide occurs shortly after the occurrence of new moon, not because the moon is dark or unilluminated, but because, when the moon is thus unilluminated, it is between the earth and sun, so that the attractive influence of the sun is for the time superadded to that of the moon in producing the tidal swell.

Now, there can be no question that the moon does produce a somewhat similar effect upon the atmosphere to that which it exerts upon the sea. As it goes round the earth, and as the earth whirls upon its axis in front of the attendant orb, a tidal swell is called up in that part of the atmosphere which is most immediately opposite and nearest to the lunar mass ; and this tidal wave in the air undoubtedly is accompanied by some change of physical state which would involve alteration of pressure, and which would be to that extent indicated by the barometer, and would tend to produce movement in the air or wind, and such weather change as is attendant upon wind. But all this, it will be observed, has nothing whatever to do with the phases, or changes, of the moon. The effect, whatever it may be, is precisely the same whether the moon is new, or half illuminated, or full. It is determined and measured only by the revolution, distance, and mass of the moon, and by the dimensions and rotation of the earth.

But as the lunar influence upon the tides of the sea—a physical effect which is as exactly appraisable by the expedients of science as the weight of a pound of lead—is accurately known, so also is its influence upon the tides of the air. Sir John Herschel, indeed, was able to show that the combined influence of the sun and moon would, in the most favourable circumstances, cause an atmospheric tide which would affect the barometer to the extent of the $\frac{1}{130}$th part of an inch. Five-sevenths, or nearly three-quarters, of this oscillation would be due to the action of the moon. But this, it will be observed, is a quantity so minute that it must be altogether swallowed up, and disappear, in the large oscillations which are caused by the heat-action of the sun, and which in extreme instances, it has been seen, amount to three inches of the column of mercury. The final result, therefore, unquestionably is that any changes of atmospheric condition that can be brought about by the shifting positions of the moon are necessarily too small to be appreciable amidst the larger vicissitudes that are incident upon other causes.

Although the old popular notion that appreciable changes of the weather can be produced by the changes of the moon must thus be summarily dismissed from the canons of modern meteorological science, there is one somewhat correlative point concerning which a qualifying word needs, nevertheless, to be said. At the time of full moon a very considerable flood of reflected sunshine is thrown back from its bright face upon the otherwise night-shadowed hemisphere of the earth. But is it clear that there is no warmth, as well as light, in this flood of moonshine? Is it certain that all the heat which undoubtedly was associated with the solar rays when they fell upon the moon has been sifted out from the light-beams which are thrown back to the earth? Various attempts have been made by scientific men to ascertain whether any trace of heat can be detected in moonlight, and the most exquisitely sensitive plans have been devised for getting a satisfactory result from the experiments. In one of these a faint indication of warmth was found by the skilful observer Melloni, who used a very delicate thermo-electric pile* in his experiments. But in the vast majority of trials the moonshine appeared to be absolutely cold. In reference to these interesting investigations, it may, however, be remarked that all the observers inclined to ascribe the coldness of the moonlight to the circumstance that whatever heat there may be in the lunar beams is absorbed by the vapours floating in the higher regions of the atmosphere, and therefore prevented from reaching the ground. If this be the case, it obviously implies that the heat reflected from the full moon does exert a palpable effect upon the atmosphere, although it does not penetrate to the solid surface of the earth. The heat which is arrested by the vapours of the air must be turned to account in increasing their rarity and transparency, and therefore in dissolving slight deposits of visible mist, such as the high clouds frequently present. Sir John Herschel was led to infer that some action of this kind is exerted by the moon in consequence of having had occasion to notice how very commonly the nights of the full moon at the Cape of Good Hope were absolutely cloudless and clear. The author's own experience of nearly nine years in the neighbouring colony of Natal substantially confirmed the impression of the distinguished astronomer. He acquired, indeed, such a confidence in the sky-clearing influence

* "Science for All," Vol. III., p. 59.

of the full moon, that he was upon one occasion, at a somewhat serious cost to his reputation as a weather Pundit, betrayed into the indiscretion of advising that the night of the full moon should be fixed for a ball which was about to be given to the officers of the garrison at Pietermaritzburg, the capital of Natal, in order to take advantage of the probability of fine weather which that contingency promised. This was a matter of rather serious importance in a small colonial town, in which close carriages were still very much in the same category as the visits of angels. On the day of the full moon, when the entertainment took place, heavy rain began to fall in the early hours of the afternoon, and it continued to fall as viciously as only tropical, or approximately tropical, rain can until far on into the small hours of the night. For a considerable time after that inauspicious act of meteorological prophecy, any exceptionally heavy rain was profanely spoken of in Pietermaritzburg as "one of the Doctor's full moons." The prophecy was nevertheless not without good justification. In eight full moons out of ten the result would have been of a more satisfactory character. The unfortunate event was simply an untimely exception to a good general rule. The failure of the prediction in this particular case was merely the consequence of the fortuitous accident of a series of disturbing influences coming simultaneously into play. A strong conflict of opposing winds had for the time overwhelmed and swallowed up the beneficent spell of the moonshine. The full moon, which is capable of dissolving thin clouds in the higher regions of the comparatively still air, is not competent to deal with the denser cloud-masses of the storm. The careful observer of weather signs, wherever he may be, will often find that with still calm air, and a slightly veiled sky, the full moon will gradually establish its ascendency, and shine out in undimmed glory with the advance of night. There must, however, be a steady barometer, and an absence of wind as well as of heavy low clouds. If, therefore, a young aspirant feels tempted, at any time, to venture upon a weather prediction in connection with the full moon, it may be as well for his reputation as a would-be seer that he shall, at any rate, make the fulfilment of his prophecy conditional upon the co-existence of these atmospheric states. Such, at any rate, is the moral which the writer here desires to point. Even the full moon only exerts a weather influence to the extent of clearing away the thin upper cloud that occasionally lingers in a settled and well-disposed state of the atmosphere.

THE ANATOMY OF ANTS.

By F. Buchanan White, M.D., F.L.S.

I Nature is most to be admired in things of the smallest size has, perhaps, no better illustration than that afforded by the ants, whether it be from their structure, their real or supposed intelligence, or their curious and varied habits. In structure, they are admirably suited for carrying out the work that has been entrusted to them; in intelligence, they surpass many other creatures of far higher rank in the animal kingdom; and in some of their habits they occupy a position only second, perhaps, to that of man himself. Though we cannot all expect to have an opportunity of seeing for ourselves everything that is worthy of notice, yet, as ants inhabit every clime and almost every place, it is within the power of everyone to acquire for himself that most excellent knowledge which arises from direct and intelligent observation; and for the rest we must trust to the information given to us by others more fortunately situated.

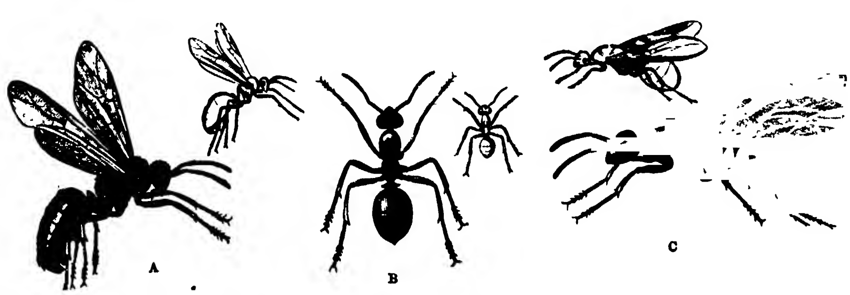


Fig. 1.—Red Ant: A, Male; B, Worker; C, Female. (*Magnified and natural size.*)

Let us proceed, therefore, to the nearest ant-city (whether this be below a stone, in a mound of earth, in a decaying tree, or [Fig. 2] in one of those large collections of vegetable débris known as "ant-

hills"), and, as it is desirable to become well acquainted with the personal characteristics of the subject of our investigation, begin by subjecting one of the inhabitants to a careful scrutiny.

It is possible that, in looking about the ant-nest for a suitable "specimen," on which to begin operations, we may notice that some of the inhabitants have wings, while others are wingless. Examining more attentively the latter, it will be seen that they are of at least two sizes. Passing by the larger ones for the present, we will select one of the smaller individuals.

Our captive, we will find, is a small, more or less elongate, animal, furnished with six legs, two antennæ, &c., and with rather hard integuments, formed of the horny material called chitine, which, as in other insects, constitutes the external (and only) skeleton, or framework, which serves for the attachment of the muscles and the protection of the vital organs (Fig. 1). This horny skin is more or less polished and shining; but examination with a magnifying-glass will show that it is not destitute of some very fine and short hairs, more abundant and conspicuous in some kinds of ants than in others.

The body, like that of other insects, consists of three chief parts—head, thorax or chest, and abdomen.

The head is more or less triangular in outline, broadest behind, and flattish below. In front, and a little below, is the mouth, furnished on each side with a generally stout and toothed horny *mandible* or upper jaw; sometimes, however, the mandibles are slender. Between the upper jaws is situated the upper lip, or *labrum*, a somewhat horny plate, usually bilobed, directed downwards, so as to cover the opening of the mouth, and attached by a membrane, which serves as a sort of hinge. Nearly concealed by the upper lip are the *maxillæ*, or lower jaws, one on each side. These are rather small, leathery in texture, and composed of three pieces, of which the terminal one is hard and rounded at the extremity, which is furnished with some strong hairs; while near the inner, or upper border, is often a row of minute elevations, which are considered to be organs of taste, or gustatory papillæ. Each maxilla is provided with a palpus, or feeler—the *maxillary palpi*—composed of from one to six joints. At the lower part of the mouth is the lower lip, or *labium*, a membranous and muscular organ, very mobile, and bearing the two lip feelers, or *labial palpi*, composed of from one to four joints. To the inner and upper surface of the lower lip is attached the *tongue*, a very mobile and extensible muscular organ, convex above and in front, and concave below, and covered above with transverse folds. Below and near the tip of the tongue are two horny plates, each provided with a strong hair; behind the tongue is a row of strong and long teeth, and on each side in front, and also on the hind border, are a series of gustatory papillæ, similar to those on the maxillæ. The parts of the mouth are all short, and more or less concealed, with the exception of the mandibles, which are often of large size and formidable appearance.

Near the front of the head are inserted the *antennæ*, rather long, relatively, to the size of the insect. Each antenna consists of a long basal joint (called the *scape*, and frequently nearly half the length of the whole antenna), and a number (8 to 13) of smaller joints, which form the *flagellum*. At the junction of the scape and flagellum, the antenna forms a very distinct angle, or elbow. The flagellum, being composed of a number of joints, has a certain degree of flexibility.

The *compound eyes* are situated upon the rounded side-margins of the head, behind the antennæ; and are elliptic in outline, and more or less convex. In some kinds of ants (as we shall see hereafter), they are nearly or altogether absent. These compound eyes are formed as in other insects, and their structure has been briefly described in a former paper. We need, therefore, only notice just now that the number of facets, of which the external surface of the eye is composed, is very variable in the different kinds of ants. Some species are said to have only one to five facets, while others have no less than twelve hundred or more.

The *ocelli*, or single eyes, are not always present, as the workers are unprovided with them. When present (as in the males and females) they are usually three in number, though sometimes reduced to one, and situated on the top of the head, one in front and two behind, and so arranged that, if we connected them by lines, an isosceles triangle would be formed. The structure of the ocelli, as of the compound eyes, has been alluded to in a former paper.

The *thorax*, or chest, which is connected with the head by a slender neck, is constructed of the usual three rings or segments, forming respectively the front chest (prothorax), middle chest (meso thorax), and hind chest (metathorax). These, in the individual ant under examination, which, from

its wingless condition and size, is most probably a "worker," or "neuter," as the workers are sometimes called, are all tolerably distinct; and their dorsal and ventral regions are termed respectively pronotum, mesonotum, and metanotum, for the dorsal; and prosternum, mesosternum, and metasternum, for the ventral. In the male and female ants (whose examination we have deferred in the meantime), these parts are more complex and not so easily made out as in the worker.

Though always consisting of these three segments, the shape of the thorax varies extremely in different kinds of ants. Each ring is provided with a pair of legs, each composed of the five parts usual in insects, viz., coxa, trochanter, femur or thigh, tibia and tarsus; the latter being made up of five joints, of which the first is much the longest. The last joint is furnished with two claws. The three pairs of legs differ only in length, the first pair being the shortest, and the third the longest; but the tibia of the first pair is provided with a kind of brush-like spur, which is used by the ant in cleaning itself.

The *abdomen* is composed of six rings or segments (except in the males, which have seven). The first segment in some ants, and the first and second in others, are rather peculiar in structure, being so considerably reduced in size that a distinct waist is formed; the segment (in the one case) or segments (in the other) appearing in the narrow waist as thickenings or "knots," which latter name has been applied to them, the whole waist being called the petiole. When there is only one "knot," it is furnished above with a variably-shaped piece called the *scale*. The rest of the abdomen is spherical, oval, elongated, or heart-shaped in form; and in some families of ants is provided with a more or less formidable retractile sting.

Having thus examined the chief features of the external anatomy of an ant (or rather of one of the individuals known as workers), we will, before glancing at the internal structure, revisit the nest, and try and find some other specimens which, while bearing a general resemblance to the one we have examined, have yet well-marked differences. Should our visit be made at the proper season of the year, it is more than likely that in or near the nest will be seen some insects much like the ant we have examined, but larger, and provided with two pairs of membranous wings. These winged individuals will be seen to be of two sizes, the larger being the females and the smaller the males (Fig. 1). A closer search amongst the ants which inhabit the nest will show us that there are a set which differ only from the winged females in that they are wingless; and a still more minute inspection of these will reveal the fact that they are female ants, which somehow or other have no wings. How this happens we shall presently see, but in the meantime we will ascertain in what respect the male and female ants differ from the workers or neuters. In the first place, the head is rather narrower in comparison with the front part of the thorax, than which in the workers it is broader, and in the males and females narrower. Both the latter are provided with simple eyes, or ocelli, which the workers never have; and the ocelli of the males are more developed than those of the females, while, on the other hand, the mandibles of the males are less developed. In the thorax there is, as mentioned above, a considerable difference, for not only are the three rings of which it is composed considerably more subdivided, and hence altered in appearance, but, as the males and females are provided with wings, room has to be found in the thorax for the muscles which work the wings, and hence it is much stouter. The pieces into which the three rings of the thorax are subdivided vary in form in different kinds of ants, and all the parts are not always to be distinguished as separate pieces. When distinguishable they are as follows:—The front chest is composed above of one piece or plate, the pronotum (often nearly covered by the corresponding piece of the next ring), and below of two pieces, which together form the prosternum; the middle chest consists above of four pieces, one behind the other, and termed respectively the mesonotum, proscutellum, scutellum, and postscutellum, and below of one piece, the mesosternum, above which, on each side, is another plate, called the scapula; the hind chest has one piece above, the metanotum, and three plates below, forming together the metasternum. From this it will be seen that the thorax of the males and females, at least on the upper surface, is much more complex than that of the workers; on the under side the difference is not so great, and the parts there have the same names in the workers as in the other individuals.

The wings are four in number, rather large, and formed of a delicate membrane, strengthened by nervures. The first pair of wings is the longest, and arises from the sides of the middle chest, being attached at a point between the mesonotum, postscutellum, and scapula. The second pair of wings is attached to the hind chest. Both pairs of wings

are more firmly attached in the males than in the females.

The abdomen also presents some points of difference, as, for example, in having one segment more in the males than in the females and workers. The males of those ants whose workers are armed with stings, have no stings, though the females have. The extremity of the abdomen presents certain differences of form, dependent on the sex of the individual, and connected with the organs of reproduction. The workers partake in this respect of the characters of the female, to which sex they in reality belong.

We will now look at the internal structure (Fig. 3). The *alimentary system*, which is on much the same plan as in other insects, commences with the mouth and its various parts. Of these the mandibles are not used in eating, and the maxillæ, or lower jaws, are not constructed for mastication, but rather as sheaths for the tongue. It is the tongue (Fig. 3, A) which is the chief instrument employed in eating, and it is used, as a dog uses his tongue, to lap up liquid, or nearly liquid food. If the food is, for example, an insect, it is cut up by the mandibles, and its juices and soft parts extracted by the tongue. Next comes the *gullet*, a long muscular tube, commencing with the pharynx and continued as the œsophagus. Into the pharynx, which is more muscular than the œsophagus, opens from below a spherical bag, called the "*buccal sac*," whose use is unknown, but which is generally filled with a somewhat solid mass of alimentary particles. Its walls are not muscular. The œsophagus dilates as soon as it enters the abdomen into what has been called the "*sucking stomach*," which is merely an enlargement of the œsophagus.

Fig. 2.—Nest of the Red Ant.

and, like it, not very muscular. This sucking stomach is usually filled with a clear fluid, and opens into the *gizzard* or proventriculus (Fig. 3, D), a horny and muscular dilatation of the alimentary canal, varying considerably in structure in the various genera of ants, and composed of three parts. The anterior portion is cylindrical, and its inner wall contains four longitudinal horny (chitinous) plates, or leaves, surrounded by strong muscles. These plates are rounded at the top, where they touch the sucking stomach, but approach closely at their lower ends, and then diverge and form a bulb, which is also embedded in strong muscles. The second part, which varies much in length, is a narrow, straight muscular tube, extending from the bulb to the third part, which is another dilatation, somewhat globular or elliptical in form, and contained entirely in the cavity of the true stomach. As already mentioned, the gizzard varies in the form of its different parts very considerably in different kinds of ants. In some the horny plates in the anterior portion are much less developed. Ants, as we shall presently see, partake of food with two objects in view: one, to nourish themselves, the other, to have a supply from which to feed the young or their hungry comrades. This is accomplished by disgorging part of the food they have swallowed, and which is stored up chiefly in the sucking stomach. The object, therefore, so far as is known, of the gizzard is to closely cut off all connection between the part of the alimentary canal in front of it from that which is behind, and so prevent any of the contents of the true stomach being disgorged along with the liquid in the sucking stomach. The horny plates described above are closely pressed together, and thus make an effectual valve.

The gizzard is followed by another dilatation of the alimentary canal—the true *stomach*, or ventriculus, which, like the sucking stomach, is capable of considerable expansion. It is followed by the *intestine* proper. The various glands, including the salivary glands, the Malpighian or urinary vessels, &c., which are attached to the alimentary canal of insects have been described in a previous paper, and need not be further alluded to. Nor need special mention be made of the *breathing* and *blood-circulatory* systems, which, for the most part, present no striking differences from the same organs in other insects. On the other hand, the *nervous system* (Fig. 3, C) is much more highly developed than it is in the great majority of

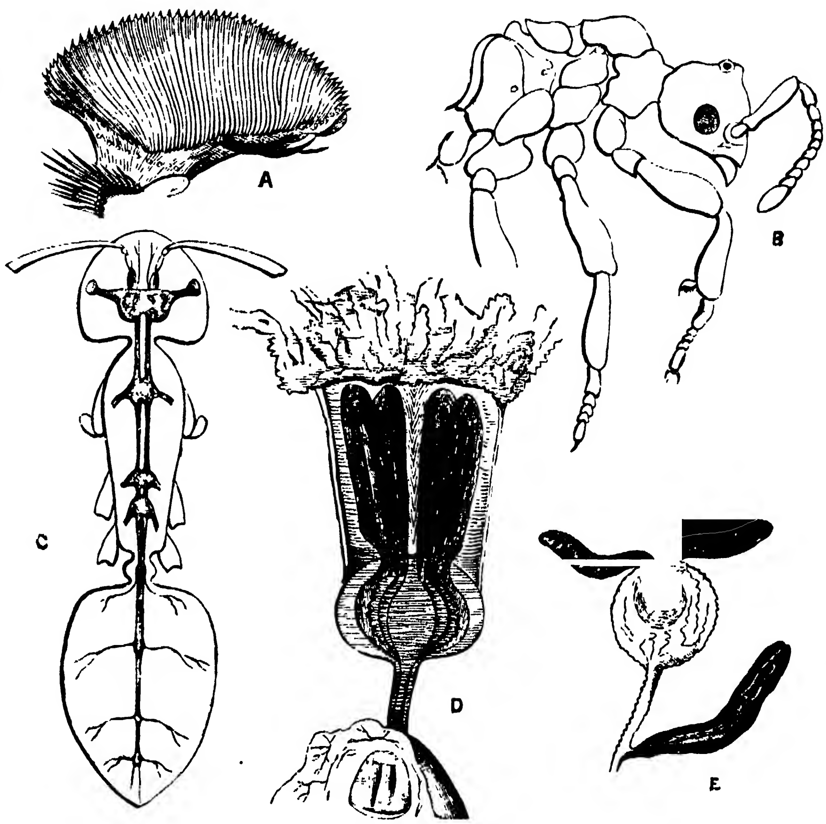


Fig. 3.—A, Tongue of Ant; B, Parts of Chest of do.; C, Nervous System of do.; D, Gizzard of do.; E, Poison Gland of do. (*After Forel.*)

insects, though, of course, the chief features are the same. The ganglions (or "depôts of nerve force") situated in the head are especially large and well developed As usual they consist of two, one (the larger) above the gullet, and the other below. Behind the former are two large nerve-masses, termed the "pedunculated bodies," and of greater magnitude in the workers than in the males and females. These bodies are more developed in ants than in any other insects. In the thorax there are three ganglions, and in the abdomen four, of which one is in the "knot" of the waist—when there are two "knots" the first only has a ganglion.

In connection with the nervous system some organs of special senses must be noticed, though,

owing to the small size of these insects, more light requires to be thrown on their structure and supposed uses. Amongst these organs is one which is believed to serve for the sense of hearing, and is to be found in the tibia of the front leg. The air-tube, or trachea, after entering the tibia, dilates into a "sac," then contracts into a tube again, and again dilates at the tip of the tibia into another "sac." A smaller tube arises from the first dilatation, and runs down the tibia and joins the main tube near the second sac. The other parts of the structure have not been very clearly made out yet. It may be compared, according to its discoverer (Sir John Lubbock), to the supposed organ of hearing in the leg of the cricket.

In the antennæ are several structures whose use is not quite made out, but some of which seem to be connected with the senses of touch and smell. There is no doubt but that the antenna is of the utmost importance to the ant, and the sense of which it is the organ is best comparable to that of touch and smell in the higher animals, though possibly it is the seat of some other sense of which we know nothing. An ant deprived of its antennæ loses the faculty of finding its way, fails to recognise friends or enemies, and even to discover food placed quite close to it. Moreover, as the sense of sight is not very highly developed in some ants (especially in the workers), and is occasionally entirely wanting, the necessity of such a sensitive organ as the antenna becomes of paramount importance. The structures that have been discovered are five in number, two internal and three external. The latter consist of—1st, thick, obtuse, transparent, club-like hairs, seated on broad "canal-pores," which look like transparent discs. These clubs are supposed to be connected with the sense of smell. 2nd, hairs much more delicate, uniform, and less horny than the ordinary hairs, and placed upon narrow "canal-pores." These are thought to be organs of touch. 3rd, another kind of hair, very broad but pointed at the tip, three-ridged, arising from a "canal-pore," and then bent and lying in a longitudinal trench. Inside these latter hairs there seems to be another hair. These three kinds of hairs are most abundant towards the tip of the antennæ, and are never to be found on the "scape," nor on the first joint of the "flagellum." The two internal structures, which are probably connected with one or other of these external organs, though this connection has not been traced, are as follows:—1st, the antenna, in addition to the muscles which move the joints, contains an air-tube (trachea) and a nerve. In the joints of the "flagellum" the nerve forms ganglion-like swellings. The last joint contains one of these swellings, in which terminate the ultimate branches of the air-tube. In connection with this last ganglionic mass are from five to twelve horny tubes, each ending in a zigzag horny canal, which ends in an annular opening in the external skin of the antenna. The tubes are united more or less into a bundle in the last joint, but isolated ones may be found in the other joints of the antenna. In their structure these tubes somewhat resemble the third kind of hairs described above. 2nd, near the annular opening just mentioned are to be found certain other horny transparent organs, resembling in shape champagne bottles. They touch the horny skin of the antenna, and also seem to be in connection with the ganglionic masses.

In describing the abdomen, allusion was made to the fact that the females and workers of some families of ants were provided with stings. The sting is a modified form of the egg depositor, and consists of a central piece, which serves as a director or guide; two slender and sharp lances, which meet each other by one of their edges, and the central piece by the other edge, and thus form a tube, by which the poison is conveyed to the wound made by the lances; and an outer piece on each side which serves to form a valvular sheath for the sting. There is a special poison-producing apparatus which is in connection with the sting in those ants which have one, but is also possessed by the ants which have no sting. The manner in which some of the latter use the poison is by ejecting it forcibly from the end of the abdomen. The method in which this is done may be easily observed by disturbing on a warm day one of the large "ant-hills" so common in many woods. If the inhabitants are numerous and much excited, the shower of liquid poison ejected makes quite a spray, rising eight or ten inches above the nest. Care must be taken not to allow any of it to get into the eyes. The poison apparatus is composed of—1st, the poison gland; 2nd, the poison reservoir or bladder; 3rd, the sting, when it is present; and 4th, the accessory gland. The poison gland (Fig. 3, E) varies somewhat in form in different families of ants. It consists of two tubes, slender or stout, which unite into one, and enter the outer skin of the poison bladder, but before piercing the inner skin go backwards and forwards till an oval or circular pad or cushion is made. Sometimes the

gland is furnished with branches. The reservoir or bladder is a transparent, flexible, and expansible bag; from it a narrow tube leads either to the sting or to the cloacal opening at the apex of the abdomen. The accessory gland varies considerably, both in size and form, which may be that of a single or bifid tube, or spherical, &c., and it is filled with a thick yellow liquid. The poison of ants has usually a very pungent odour, and has, as a constituent, formic acid.

Though ants have no voice, in the true sense, yet some of them can produce a sound. This is accomplished by one of the abdominal rings being rubbed on another, the parts thus brought into contact being distinctly provided with raised striations. The sound produced is somewhat of the nature of a whine, and seems to be a sign of irritation or anger.

Having now seen what are the chief peculiarities exhibited by the structure—external and internal—of the adult ant, we must devote a little attention to the preparatory stages which they, in common with all insects, pass through. The materials for direct observation of these will be found in any ant's nest, if we look for them at the proper season, *i.e.*, usually throughout the warmer months of the year (Fig 4).

The *egg* is the first stage; and here, it may be remarked, that what are popularly called "ants' eggs," are not the eggs at all, but the pupæ (or third stage) enveloped in their cocoons, and very many times larger than the true eggs. The eggs when first laid are elongate in form, and opaque white, or yellowish in colour. In size they vary, of course, according to the different species of ant to which they belong. The eggs that will produce male, female, or worker are identical in appearance. The most remarkable fact connected with ants' eggs is that they increase in size, becoming at the same time transparent, and curved at one end. This increase of size is almost peculiar to the eggs of the ant amongst insects: and it is thought that the workers in taking care of the eggs—which is one ot their most important duties—convey nourishment to the enclosed embryo by endosmosis, that is to say, the contents of the egg are able to absorb, through the covering membrane, liquid food, though there is no opening or mouth by which it can visibly enter. The egg is usually hatched in about a fortnight after it is laid.

The next stage is that of the *larva*, which is in the form of a small white grub or maggot, whose body is composed of twelve rings or segments, often indistinct (Fig. 4, A). The larvæ of the different kinds of ants vary somewhat in form: some being thick at both extremities; others narrower in front; some are very mobile; others stiff and almost incapable of movement. The head end is usually curved, and the skin more or less covered with fine hairs. The mouth shows some of the parts of the mouth of the adult ant, but only in a rudimentary condition. Thus we can trace the rudiments of the two mandibles; of the maxillæ, which are soldered together into one soft central piece, notched in front and furnished with two short, thick, horny hairs on each side; and of the lower lip, which is soft and retractile.

The duration of life in the larval condition varies according to the season of the year and the kind of ant. Sometimes it is less than two months; at others, larvæ hatched in autumn do not change to pupæ till the following July. During all their life the larvæ are dependent upon the workers, who nurse and feed them; they are quite incapable of taking care of themselves. As they increase in size they moult, or change their skins, but how often this is done is yet uncertain. When the larva has attained its full size, and the time has arrived for it to pass on to the third or pupa stage, it begins to envelop its body in a cocoon of fine silk threads, till it is entirely enclosed and hidden in an oblong oval case of close texture (Fig. 3, C). Within this it throws off its skin and becomes a pupa or nymph (Fig. 3, B), and remains there till the final change to the perfect or adult condition takes place. The cocoon varies in colour and in the thickness of its walls in the different species. It is usually of a white or pinkish yellow tinge, and not very strong in texture. But the larvæ of all kinds of ants do not make cocoons. Some change to pupæ without doing so; and even amongst

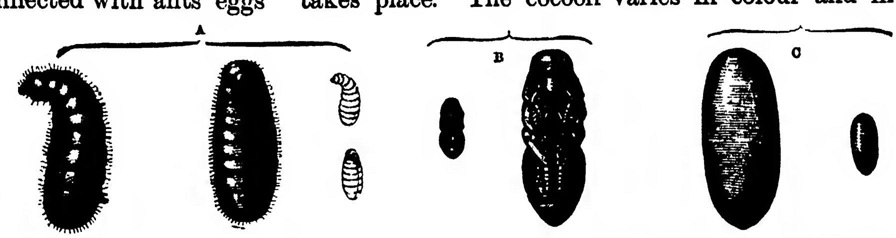


Fig. 4.—Larva, Nymph, and Cocoon of Red Ant. A, Larva, seen sideways and from above (*magnified and nat. size*); B, Nymph, seen from below (*magnified and nat. size*); C, Cocoon of Nymph (*enlarged and nat. size*).

the ants that usually make cocoons, individuals may be found which do not.

In the *pupa* or third stage all the limbs, except the fully-developed wings, of the adult insect are to be seen, but enveloped in a close-fitting membrane, which forms for the antennæ and legs (which are folded on the breast) distinct sheaths. The pupa—even when not enclosed in a cocoon—cannot move about, does not increase in size, and does not, of course, partake of nourishment. In colour it is at first white, but soon the eyes (seen through the transparent enveloping membrane) change to brown, becoming gradually darker; and, as the insect approaches maturity, a general change of colour takes place, and it becomes somewhat of the tint of the adult ant, whatever that may be. Just as they did for the eggs and for the larvæ, the workers take complete charge of the pupæ—whether these be in cocoons or naked—carrying them about from one part of the nest to another, according to the temperature, watching over them and cleaning them. As the larva, in spinning its cocoon, probably attached to it particles of earth or fragments of the débris which composed the nest, the workers carefully clean and smooth it, and, finally, when the time has arrived for the pupa to be hatched, they assist the young adult to make its escape from the cocoon, for it cannot do this itself, and should not the worker cut open the cocoon the inmate of it perishes.

It is decidedly remarkable that the workers should know when it is time to let out their nurselings (for the duration in the pupa state is a little variable), but M. Forel, in whose work on the Ants of Switzerland much interesting information may be found, has observed that, after the pupa has become mature, there is a sufficiently long period during which the workers can select their own time for opening the cocoon and extracting the pupa. The latter can then throw off the membrane in which it is invested, and become an adult ant. Though this last moult can be performed without the assistance of the worker-nurse, the latter, no doubt, often helps, especially with the males and females who have a difficulty in disengaging the tips of their legs and wings.

Having now traced an ant through the various metamorphoses that it has to undergo, and having seen the chief details of the structure of the perfect ant, we must pause to inquire to what order of insect it belongs. From the dissimilarity of the larva to the perfect insect, we have no difficulty in deciding that it belongs to those orders which are said to have a perfect metamorphosis, and are hence called metabola or metabolous. In the next place, the structure of the adult's mouth places the ants amongst the insects which are furnished with mandibles; and, lastly, the possession of four membranous wings separates them from the beetles or Coleoptera, which have the front wings leathery. Thus we arrive at the conclusion that they belong to the Hymenoptera (so called from the membranous nature of their wings), and find their nearest relatives amongst the bees, wasps, ichneumon-flies, &c. We can then pursue our inquiries farther, and, from the knowledge we have acquired of the anatomy of the ant, find that its place in the order Hymenoptera is amongst those whose females and workers are provided with a sting or poison gland (though, as we have seen, the sting is sometimes abortive), and which, consequently, are termed the "Aculeate Hymenoptera." Proceeding a little farther, we find that they cannot belong to the large family of the bees (there are many other kinds of bees besides our familiar acquaintances—the hive and humble bees), because the basal joint of the hind tarsus is not, as in the bees, flattened and widened to form a basket for carrying pollen. Finally, we discover that our ants, having wingless workers, cannot find a place in the group called "Fossores" (of which the wasps are the most distinguished members), whose workers, when they have any, are provided with wings; and so at last we trace them home to the group "Heterogyna," so called because of the two kinds of females, viz.: the fully-developed and winged females, and the wingless workers, or so-called neuters.

A LUMP OF SUGAR.

By David Houston, F.L.S.,

Author of "Practical Botany for Elementary Students."

SUGAR, it is well known, exists in many varieties of form, each differing from the other in certain physical and chemical particulars; but sweetness and ready solubility in water are two of its constant and most characteristic properties. If we examine the structure of a lump of loaf-sugar, we find that it is built up of an immense number of small, sparkling, transparent crystals. Proceeding to break the lump, we find that the particles are very easily separated, in consequence of which the body is exceedingly brittle. An explanation of this lies in the fact that the shining faces of the many crystals seen on both the fracture surfaces were planes of weak cohesion.* To understand it more clearly, get some large crystals of sugar—such as are found in sugar-candy—and, with a knife-blade, attempt to split a crystal in different directions. Now notice that there is one direction in which the crystal refuses to split, while there is another direction along which it will split quite easily, enabling us to remove again and again thin shining layers from the crystalline mass. These cleavage planes, as they are called, are therefore surfaces of weak cohesive force, and hence the fissile character of all crystalline bodies. If, for the purpose of comparison, we here destroy the crystalline structure of the lump of loaf-sugar, by placing it in a metal spoon and holding it over the flame of a lamp until it melts, we can see at once, upon an examination of the cooled yellow mass, the marked difference in physical condition existing between a crystalline and uncrystalline variety of the same body.

Sugar is highly soluble in water, but scarcely soluble at all in alcohol. It crystallises from its aqueous solution when slowly evaporated, forming oblique six-sided or four-sided rhomboidal prisms (Fig. 1). They are well seen in the sugar-candy. Now let us fully understand what being soluble in water really means. If we put a few lumps of sugar in half a glassful of water, and keep stirring it with a rod, we shall see the lumps gradually disappear, until at last not a particle of the sugar is to be seen. In fact, the crystals of the sugar have suffered most extreme subdivision, the separated particles being so small that it is absolutely impossible to discover their presence by any known optical means. The substance, however, has undergone no chemical change; the sugar is still present in the liquid, as may be readily tested by the sense of taste, or we may bring the sugar back again to its original state by completely evaporating the water, thus compelling the little particles of sugar that are left behind to become gradually deposited, and these, wonderfully and definitely arranging themselves in groups, form, as the liquid disappears, hosts of little similarly-shaped

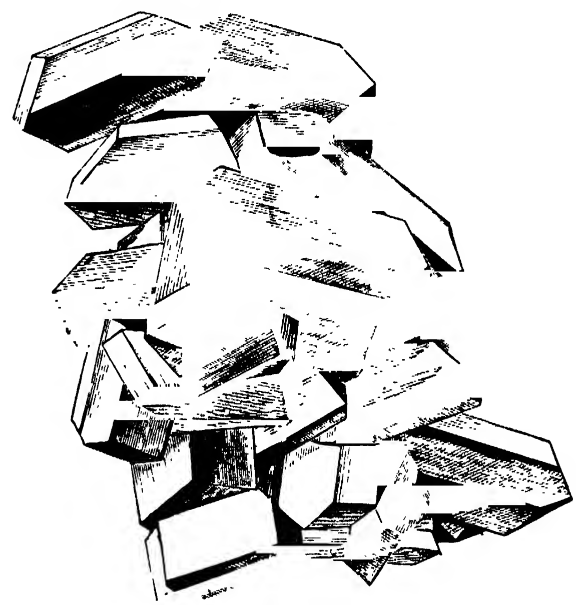


Fig. 1.—Crystals of Sugar.

crystals of beautiful form. The addition of a little salt to the original solution, it may be noted, renders the deposition of the sugar and the formation of crystals much more difficult, as salt readily combines with about six times its own weight of sugar, and forms a very soluble compound. The rapidity of solution of sugar, and all other solid substances, depends very much upon the state of division of the particles, as is exemplified by the more easy solubility of pounded loaf than ordinary lump. A given quantity of water, however, will not dissolve an unlimited amount of sugar. If we still keep adding sugar to the liquid it will be found that a certain point is reached, beyond which the water can dissolve no more, and any farther additions of sugar will simply fall to the bottom of the vessel. The solution is then said

* "Science for All," Vol. II., p. 189.

to be saturated. Cold water dissolves three times its own weight of sugar; hot water a little more. Temperature, however, in this case influences more the rapidity of solution than the amount of substance dissolved. A cup of hot tea, it is well known, dissolves sugar much more rapidly than a cup of cold tea. Further, it is found that stirring the tea also hastens the solution of the sugar. The reason of this is, that, the liquid being still, that portion of it in the neighbourhood of the stationary

Fig. 2.—Experiment showing the Conversion of Sugar to Charcoal.

dissolving lumps becomes fully saturated, and further solution is practically stayed. By stirring it, fresh portions of the tea are brought into contact with the undissolved mass, and solution is speedily effected. By such means, then, our lump of sugar may be mechanically broken up, the process being so complete that the cohesion existing even between its ultimate particles is overcome, and its molecules of inconceivable minuteness are separated one from another.

Is it possible to still further reduce our lump of sugar? We shall see. Chemists tell us that each molecule of sugar is made up of the solid element carbon, or charcoal, and the compound substance water. Water, as we have already learned,* is composed of the two elementary gases, oxygen and hydrogen, in the proportion of two of the latter to one of the former. It is a substance for which oil of vitriol, or sulphuric acid, has a strong chemical affinity, as may be easily demonstrated by adding a few drops of the acid to half a wine-glassful of water. The action of combination is so intense and energetic that a considerable amount of heat is generated; so much so, indeed, that the glass becomes quite hot. This affinity of the acid for water may be taken advantage of in showing the chemical composition of sugar. Pulverise a lump or two, and place the powder in a large cup, or empty mustard-tin, then pour over it a few drops of sulphuric acid, and observe the rapid change. The water in the sugar dissociates itself from the carbon, and unites energetically with the acid, and at the end of a few seconds a black mass of amorphous carbon is all that remains of the sugar. The water may also be separated from the carbon in sugar by means of the force of heat. Pound up a few lumps as before, and empty the powder into a test-tube, flask, or other suitable vessel, and heat it gently over a lamp-flame (Fig. 2). The crystals break up, and the powder readily melts into a yellowish-coloured liquid, and water, in the form of steam, is rapidly driven off. Continuing the heat, more water is expelled, the liquid gets denser, and the colour gradually changes to an orange hue, with little dark specks occurring here and there. Eventually, however, the volume of expelled steam decreases, the mass swells, becomes quite black, and in a few seconds more nothing remains in the tube but a quantity of rather spongy-looking charcoal.

It is thus easy, by the aid of chemical or heat force, to resolve sugar into its simple constituents, but all the manipulative skill of the chemist is unable to build up sugar again from these elementary bodies. This process can only be successfully accomplished through the agency of vegetal vital force. Green plants are specially concerned in the process. The soft tissue between the veins of a leaf is, as we have already seen,* made up of a great number of little thin-walled cells, each full of the plastic semi-fluid substance, endowed with life, called protoplasm. Imbedded in the protoplasm are the little green grains called chlorophyll grains, which, during the presence of sunlight, seem to take an active part in the work going on in the cell. Water absorbed from the soil by the roots of the plant finds its way into the leaf, and thence into these chlorophyll-bearing cells. Carbon dioxide (CO_2), always present in the air, also finds its way into the leaf through the pores or stomata, especially abundant on its under-surface, and thence also into the cells. Here, during the continuance

* "Science for All," Vol. II., pp. 62—70.

* "A Fallen Leaf:" "Science for All," Vol., I., p. 21, Fig. 3

of sunlight, the compound gas is decomposed by the protoplasm, the chlorophyll grains doubtless taking an important part in the operation. The carbon is then, under the same or similar influences, made to chemically combine with the water, and the result is generally the formation of starch, though sometimes of sugar. Upon examining a properly prepared section of a recently active leaf under the microscope, minute grains of starch may be seen imbedded in the chlorophyll grains. Their presence may be easily detected by causing a weak solution of iodine to run over the section, when the starch-grains will instantly be stained a bright blue colour. Starch is an insoluble substance, and so long as it remains in this condition in the leaf it is unable to be distributed by the sap throughout the rest of the plant's body; but under the influence of certain forces, physical, chemical, or vital, it may be variously modified into soluble compounds. One of its forms of modification is sugar, and changes resulting in the formation of sugar from starch take place in the leaf, and other parts of the plant's body. Hence all green plants contain a certain amount of some kind of sugar in their sap. The table here given shows (according to analyses made by Professor Church) the comparative amounts of sugar present in particular parts of the following plants :—

	In 100 parts.
Apple (fruit)	6·8
Beet (root)	10·0
Carrot (root)	4·0
Celery (leaf stalk)	2·2
Date palm (fruit)	54·0
Grape vine (fruit)	13·0
Sugar-cane (stem)	18·0

This sugar (with other substances) is used by the plant as a material for the construction of its tissues. When it is formed in any considerable excess of the present needs of the plant, it is generally stored away in particular parts of its body in anticipation of future wants. Thus in the sugar-cane it is deposited in the stem, to be used by the plant in the exhaustive period of flowering; in the bulbous roots of the biennial beet as an accumulation of food for its second year's growth; and in the fruit of the apples as a source of nourishment for the young plants which will eventually grow from the contained seeds. Thus we see that all our supplies of sugar must come from the vegetable kingdom, and that if we desire to obtain the maximum amount of sugar from any particular plant, we must wait until the plant has manufactured its full complement of reserve material, and then extract it before the plant draws upon this supply for further growth and development. There are several plants from the juice of which sugar is now extracted, the principal of which are the sugar-cane, beet, sugar-maple, sugar-grass, and certain species of palms. The sugar-cane yields us perhaps the largest supply. It is a stout grass, with a stem generally varying in height from six to twelve feet, with a diameter from one-and-a-half to two inches, the nodes or knots being separated by internodes varying in length from three to five inches; the linear leaves are three or four feet long, with stout white veins running parallel with the length of the leaves. The stem terminates in a clustering head of small white flowers. It requires for its successful cultivation a rich soil in a tropical country, and is invariably propagated by cuttings. It is grown extensively in the West Indian Islands; but it is said to be a native of the old world, and, although unknown to the Greeks and Romans, was cultivated in India, China and the South Sea Islands before the time of authentic history. It seems, however, that about three-and-a-half centuries ago the Spaniards brought it over to St. Domingo from the Canary Islands, and from thence it was transplanted to various other parts of the West Indian Islands.

When the period of flowering arrives, or just immediately after the expansion of the flowers, the sap of the stem is rich in sugar. The younger, and therefore growing, portions of the stem use up their supply of sugar for purposes of growth; and hence, when the stems are now cut down near their base, the growing parts are cut off and removed with the leaves. All injured parts are also carefully removed, to prevent hasty fermentation in the juice.

The process of extraction of the sugar has already been briefly noticed.* It is commenced by expressing the juice from the stalks, by passing the canes between heavy rollers. The collected juice is then heated with lime, for the purpose of removing the free acid, after which it is heated to 60° Centigrade (140° Fahr.), to coagulate its contained albumen, and thus prevent the fermentation which would otherwise take place. The clear liquid is next evaporated in open pans, and then crystallised in open troughs, in the meantime being briskly stirred. A solid (raw sugar) separates from the molasses, which is next strained and then dried in the sun, in which state it is usually imported into this country.

* "Science for All," Vol. I., p. 274.

The process of refining is principally carried on in Liverpool, London, Bristol, Glasgow, and Greenock—the chief seats of the trade. The raw sugar is dissolved in water, to which is added a little lime, ground bone-black, and albumen (such as the serum, or watery portion of bullock's blood). It is then boiled by steam, which causes the albumen to coagulate, carrying with it the impurities in the juice. The bone-black partially decolours it, but the clear liquid is made to pass through a filter of animal charcoal, which completes the decolorisation. The juice is next evaporated in pans, *in vacuo*, which reduces the boiling-point of the liquid from 110° C. to 65° C. (230°—149° Fahr.). The resulting syrup is run into coolers, and well stirred: it is then poured into moulds, where it cools slowly, and becomes in a short time white, sparkling, crystalline sugar-loaves.

Great supplies of sugar are also obtained from the beet plant, which is extensively cultivated for this purpose on the Continent. The bulbous roots, which, on the average, contain about thirteen per cent. of sugar, are from three to six inches in length; but it has been observed that the smaller the size the greater the proportion of sugar. It requires for its successful cultivation a deep, well-drained soil, with an abundance of soluble potash salts; but the presence of common salt in the soil renders difficult (for reasons previously stated) the crystallisation of the sugar from the juice. Hence the great loss occasioned by growing these plants for this purpose upon soil near the sea-coast. About September the roots are removed from the ground, stripped of their leaves, and stored away in pits. Much care is required to prevent the roots from sprouting before being sent to the works, as this would, of course, occasion considerable loss of sugar. The process of manufacture is, in the main, almost identical with that pursued in the treatment of the sugar-cane, with this exception, however, that the juice of the beet-root being sticky, its extraction is usually effected by maceration instead of pressure.

There are several varieties of sugar, but the three principal kinds are cane, grape, and milk sugar.* The sweetest variety is cane-sugar; it crystallises in oblique six or four-sided rhomboidal prisms, and emits a phosphorescent glow when struck, rubbed, or broken in the dark. It is 1·606 times heavier than water, and turns a ray of polarised light 73° 8′ to the right. It is principally derived, for commercial and domestic purposes, from the sugar-cane, beet, and sugar-maple; but it occurs in smaller proportions in the juices of other plants—the mallow, for instance.

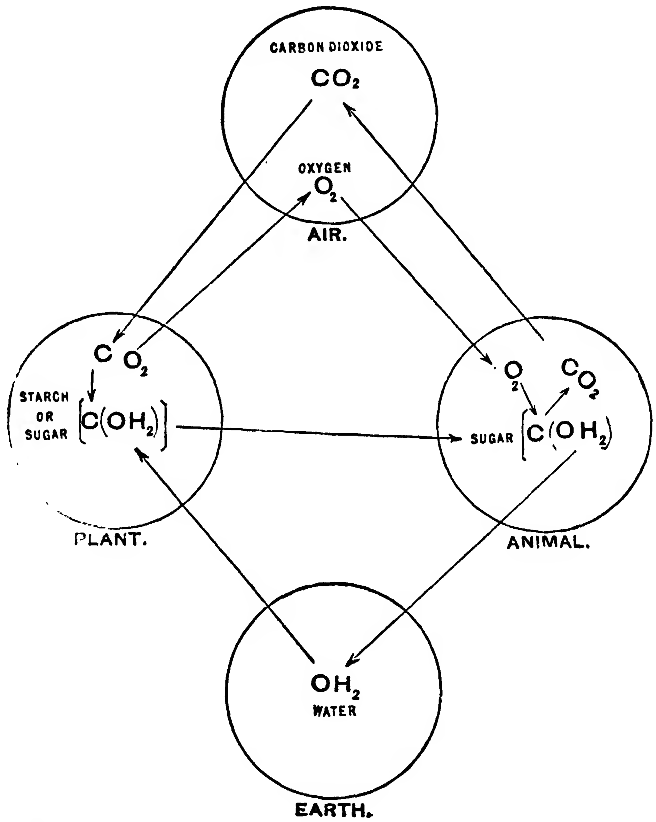


Fig. 3.—Diagram showing the Cyclic Changes resulting in the Formation, Decomposition, and Recomposition of Sugar

Grape-sugar is twenty-nine times less sweet than cane-sugar, and is found plentifully in the juice of all succulent fruit. It is readily formed from starch in the plant or animal body. It may also be easily produced from this same substance in the laboratory by slow boiling in dilute acid, and is sometimes prepared from paper, cotton, and linen rags, and even from sawdust, by the same process.

Milk-sugar is found in the milk of all the mammalia, but, of course, in varying proportions; cow's milk containing 5·1 per cent., and woman's milk 6·9. It may be obtained in its characteristic rhombic crystals by slow evaporation. It is not so soluble in water as either cane or fruit-sugar, and is also considerably less sweet to the taste.

Sugar is universally used as an article of food or luxury, and its importance in domestic economy cannot possibly be over-estimated. Even in countries where it is not obtained in a separate form, it is eaten extensively in fruits, and other kinds of

* "Science for All," Vol. I., pp. 273, 274.

vegetable and animal foods. It is one of those foods which are necessary for the maintenance of heat throughout the system, and consequently tend to keep up the movements of the body. The heat is generated by the burning or oxidation of the carbonaceous compound in the presence of a constant supply of free oxygen in the blood, kept up by the repeated indraughts of air into the lungs in breathing. Under this influence of oxidation the sugar is broken up, the oxygen unites with the carbon, and forms carbon dioxide, and the water is liberated. According to Dr. Frankland, ten grains of lump-sugar, when burned in the body, produce heat sufficient to raise 8·61 lbs. of water 1° Fahr., which is equal to lifting 6,649 lbs. one foot high. The gaseous carbon dioxide—or "carbonic acid gas"—is absorbed by the blood as soon as generated. The blood eventually finds its way to the lungs, into the air-cells of which the gas is speedily diffused, and from thence it is expelled in each expiratory act in respiration.

We have now seen (Fig. 3) that sugar is a readily soluble and highly crystallisable organic compound, manufactured by plants from carbon derived from the carbon dioxide which exists as an animal impurity in the air, and water obtained from the soil; that when eaten by animals it is burned in their bodies, thereby producing much heat, the oxygen necessary for the process being supplied from the air; and also that the gaseous product of combustion, carbon dioxide, is expelled by the lungs into the air, thereby polluting it. And we have further seen that the oxygen thrown off by plants, when building up the molecular structure of sugar from carbon dioxide and water, is taken up by animals to enable them by oxidation to pull down this same structure, and reduce it again to the two original and simpler inorganic constituents—carbon dioxide and water—and that this operation is necessary during life to enable them to keep up the temperature of their bodies.

PETROLEUM.

By David Bremner,

Author of "The Industries of Scotland."

THE appearance of petroleum, or rock-oil, is so familiar to every one that it would be almost superfluous to describe it. It is one of a series of bituminous substances found in many parts of the world, and in geological formations of widely different ages. The substances to which it is closely affiliated are naphtha—a name it sometimes bears—which is more fluid, and asphaltum, which occurs in a solid form. Petroleum is generally obtained of the consistency of tar, is of a brownish colour, unctuous to the touch, has a strong odour, and is pungent and acrid to the taste. Neither it nor its allies are soluble in water or in alcohol; but the more dense may be dissolved in the more fluid of the series.

What, then, is the origin of this substance? On this point various theories have been advanced. The fact of its being found in connection with the coal measures points to a common parentage with the turpentine oils and resins of the coniferous trees which entered into the composition of the coal beds. But as petroleum is found abundantly in some of the older rocks, which contain only animal remains, there is proof that the oil may be derived from decomposed animal matter as well as from vegetable remains.

Some of the localities in which petroleum is found are subject to remarkable phenomena. The American consular agent at Maracaibo has given an account of a singular deposit of the oil which exists between the Rio Tara and Zulia. Near the former, he tells us that there rises a sandbank about thirty-five yards in diameter and ten yards in height. On its surface is visible a collection of cylindrical holes, apparently artificially made and of different diameters, through which streams of petroleum, mixed with boiling water, gush forth with great violence, accompanied by a noise as though two or three steamers were blowing off steam. The column of vapour that ascends would doubtless be seen from a long distance were it not shrouded by the thick forest, to which the petroleum beds that lie underneath give a perpetual freshness of foliage. A curious phenomenon has been seen in Venezuela, consisting of a frequent lightning without any explosion, which is observable from the bar at the entrance of the Lake of Maracaibo, close to the island of Hajoseco, and which Codazzi attributes to the vapour ascending from the Cienega de Agua Caliente. This appearance, called by mariners "El farol de Maracaibo," is more probably due to the

inflammable gas that permeates the whole district to such an extent that it is known by the natives as El Inferno, or Hades.

Though it is only within the last thirty years that petroleum has become an important article of commerce, it has been used in the arts for forty centuries at least. The mortar employed in constructing the walls of Nineveh and those of Babylon had a proportion of petroleum mixed with it, for the purpose, apparently, of securing greater cohesion and excluding damp. Traces of the bituminous matter are very distinct in the ruins, and the existence of petroleum springs at Is, about 120 miles from Babylon, indicate one source of the supply. In the ancient history of several Eastern countries allusion is made in unmistakable terms to the existence of petroleum springs. Persia, India, Java, Italy, and the shores of the Caspian (Baku), are especially mentioned as having had oil springs at a very remote period, and their supplies are not yet exhausted. Plutarch has handed down to us an account of a "sea of fire," or lake of burning pitch, which existed in Ecbatana in his time, and the ever-burning fires of the pagan shrines are supposed to have had their source in springs of petroleum. Rock-oil has also been known in England and France for centuries.

Petroleum, as already indicated, has been found over a wide range of strata. In the United States it occurs chiefly in the sandstones which form the summit of the Devonian series, while in Canada it is obtained from lower formations. Where the strata have been most disturbed, it is found most abundantly, the fissures affording room for it to collect in. In many cases it rises to the surface when the cavity in which it exists is tapped; in others, it has to be raised by pumping. This depends upon the manner in which the petroleum is disposed, and the point at which the receptacle is pierced. In Fig. 1, we have a fissure filled with water (*a*), oil (*b*), and gas (*c*). If the borer in search of oil should pierce the part of the cavity filled with water, he will find that fluid rise in the bore, and probably under the pressure of the oil and gas it will ascend in a jet to a considerable height above the surface. After the water is got rid of, by being allowed to flow away, the oil will appear in the bore; but by that time the expansive power of the gas may be so much reduced that it is unequal to forcing the oil to the surface, and the latter must be drawn by pumping. Should the explorer be fortunate enough to "strike ile," as the phrase is, he will have his reward at once, as the fluid will flow freely after being tapped. In the case of the boring tools first reaching the part of the chamber occupied by the gas, a pause must be made until that blows off, and then the oil may be extracted by means of a pump.

The crude petroleum, which is by no means so

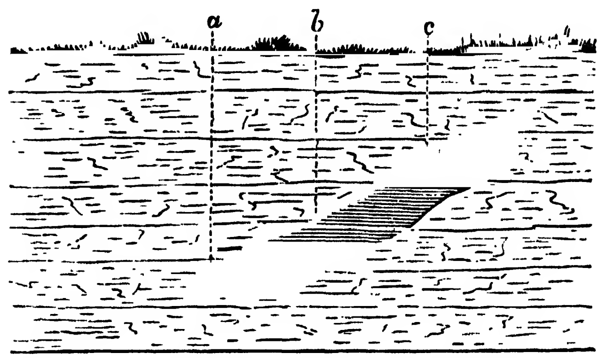


Fig. 1.—Fissure in Stratified Rocks filled with Water (*a*), Oil (*b*), and Gas (*c*).

clear or presentable a liquid as the oil we are familiar with, is converted into various commercial products by distillation. Under this treatment it yields the following substances in the proportions indicated:—

Gasolene	$1\frac{1}{2}$
Refined Naphtha	10
Benzine	4
Refined Petroleum, or Kerosene	55
Lubricating Oil	$17\frac{1}{2}$
Paraffin	2
Loss, Gas, and Coke	10
	100

The still used is of simple form, consisting of a vessel furnished with a wrought iron worm-pipe, the latter being enclosed in a tank filled with cold water. The still having been charged with crude petroleum, and the fire lighted, a vapour soon rises from the surface of the liquid, and traversing the worm becomes condensed into a liquid, which flows into a tank provided for its reception. The more volatile components of the crude oil soonest yield to the heat, and the fluid first separated has a gravity of 95° Beaumé. As the evaporation proceeds, the product becomes more dense. When the specific gravity has reached about 60° Beaumé, the fluid from the worm is diverted into a second tank, and allowed to flow until 38° Beaumé is reached, or until the oil assumes a yellow colour. The first of the two liquids thus obtained is crude naphtha, and the second is burning oil, and they but require some further purification to fit them for use; but the fluid in the still is not yet exhausted. The

stream from the worm is turned into a third tank, the fire urged, and paraffin oil is obtained. This is the last product of this preliminary distillation, and when it has passed over, there is nothing left in the still but a quantity of coke.

Crude naphtha is subjected to further distillation, when it yields in succession gasolene, benzine, and refined naphtha. Sometimes it is poured into the oil wells for the purpose of clearing them, but a less legitimate use to which it is put is the adulteration of the crude oil sold to refiners. At some oil works it is customary to blow steam through the crude oil before distillation, and thus get rid of the naphtha.

In order to render the burning oil fit for use it is purified by the addition of about two per cent. of sulphuric acid, which acts at once as a deodoriser and an improver of the colour. The oil having been poured into a suitable vessel, the acid is added, and the whole agitated for some time. It is then allowed to settle, when a tarry residuum is seen to have been separated. The oil is then poured off into a fresh vessel, and washed by the admixture of a quantity of water, with which it is agitated. Caustic soda or ammonia is then added to the oil, which is further agitated. These clarifying ingredients having fulfilled their office are drawn off, and the oil is left beautifully clear.

Owing to the cupidity of refiners, in sending into the market burning oils containing a large proportion of naphtha, which is a much cheaper substance than the oil, many serious explosions have occurred, and it has been necessary to take legislative measures for the protection of the public. No oil that flashes at a lower temperature than 100° Fahr. is considered safe. Experience has shown that one per cent. of naphtha added to an oil which flashed at 133° Fahr. caused it to flash at 103°, the addition of five per cent. caused it to flash at 83°, and ten per cent. at 59°. Common kerosene, which has a gravity of 47° Beaumé, flashes at 86° Fahr., and hence the danger of using that oil.

It may be useful to quote here a passage from the evidence given before a Parliamentary Committee by Sir Lyon Playfair. He said :—"I would burn no oil in my house, nor would I advise a friend of mine to burn any in his house, under 120° Fahr. as the very minimum; but I should prefer 130°—that is to say, 120° for the vapour and 130° for the permanent ignition. Oil with a high firing-point gives out more light than the other kind. It burns quite as long and gives out more illumination. A gallon of oil at 130° of permanent ignition produces twenty-five per cent more light than a gallon at 100°. The light from the low-igniting oil is not more at the time it is burning; but those who are accustomed to burn light petroleum sometimes like it better than heavier and safer oils, as they find that they can manage the wick more easily."

Under the name of Rangoon oil, refined petroleum was extensively used in this and other countries as a lubricant for machinery long before the great sources of supply in America were tapped. The mode of working the wells in Rangoon when the oil ceases to flow to the surface is very primitive. A small earthenware vessel is lowered into the well by means of a cord, and when filled is drawn up smartly by a labourer seizing the cord and running off in a straight line until he brings the vessel to the surface. The trade in the oil thus obtained was at one time so extensive that ships were specially built for carrying it in bulk. Seneca oil, so called after the tribe of North American Indians who discovered its merits as an application to cuts, bruises and burns, and supplied the market with it, was nothing else than petroleum collected from the surface of pools and purified in the simplest way.

The petroleum trade of the United States, which has obtained such gigantic dimensions, is of very recent origin. Prior to the year 1859, the petroleum springs which existed in various quarters were mainly regarded as natural curiosities. Persons who had learned from the Indians the medicinal properties of the oil, collected small quantities of it by spreading blankets on the surface of the springs. On being wrung from the blankets the oil was bottled and added to the household stores. In the year named, Mr. E. L. Drake, of Titusville, Pennsylvania, saw his way to a trade in oil, and sought to improve the supply by boring. Like other pioneers he was regarded as a dreamer, and people laughed at the idea of tapping a subterranean oil lake. It was only by alleging that he was in search of a bed of salt that he was able to get drillers to work for him. When the bore had reached a depth of about seventy feet, Mr. Drake found his anticipations realised, and he was the possessor of an oil well which, with the aid of a hand-pump, yielded twenty-five barrels per day. It was difficult then to find purchasers for such a quantity of petroleum, as the value of the article had not yet been appreciated. But in the course of a little time purchasers were found not only

for the produce of Mr. Drake's well, but for that of thousands of others in various parts of the United States and Canada. Some idea of the extent of the trade may be obtained from the fact that, in 1883, the Baku wells produced 5,000,000 barrels, bringing the total production of the world up to 35,000,000 barrels—of 40 gallons each. The carriage of the oil by rail being considered a drawback by the Pennsylvanian well-owners, they have constructed lines of pipes leading to the various ports, and through these the oil flows by gravitation. By this and other means the cost of the article has been reduced considerably. A dollar per barrel of forty gallons is considered a fair price for crude oil; but it has been down to nearly half that sum.

As there is no source from which the wells can be replenished, they cease to yield after a time, the period being determined by the extent of the accumulation of oil that has been tapped. Many of the most famous wells are now dry, but fresh ones are continually being sunk, so that the supply is kept up. It is rather soon to speak of the complete exhaustion of the petroleum deposits; but that it will come about some day is inevitable, and probably long before the coal-beds are worked out.

THE EARTH'S TREELESS REGIONS.

BY PROF. J. D. WHITNEY, CAMBRIDGE, MASSACHUSETTS.

THE earth's surface presents itself for study and observation with a wonderful variety of form and character. In the first place we find, as we travel over it, that we have to accustom ourselves to great changes of temperature; the range—as measured by the Fahrenheit thermometer—to which the traveller may be exposed, between the burning sands of the Desert of Sahara and the regions of the frozen north, being as much as 200 degrees. Even to one remaining on the same spot, it may,

Fig. 1.—CACTUS COUNTRY, ARIZONA. (*After Schott.*)

as the seasons vary, reach fully three-fourths of that amount. The most rapid change of climate may, however, be made by rising or descending in altitude. A few hours' climb will carry the traveller from a tropical heat to eternal snow and ice. The change from a very moist to an exceedingly dry climate is another familiar experience of every person who has given a moderately wide range to his journeyings.

The form of the surface depends chiefly on the character of the underlying rocks, and the diversities of condition to which these have been subjected during the lapse of the geological periods. Rocks, however, both in form and character, repeat themselves all over the world. The most skilful geologist could not, if dropped at random anywhere on the earth's surface, place himself, or make out approximately in what region he was, from an examination

Fig. 2.—Encampment on the Plains, Western United States (near Fort Hall).

Diversity of surface is another and an important element in the sum-total of impressions made upon the mind as any particular region of country is looked upon by even the least reflective traveller. The manifold varieties of form which exhibit themselves in plain, valley, gorge, cliff, and precipice, make up one of the essential elements of what we call the landscape. These varieties of surface may exist in any latitude; but their whole character is liable to be profoundly modified by climate, which not only manifests itself to our feelings, but influences the whole character of vegetable as well as of animal life, although the latter does not form properly a part of the landscape itself.

of the rocks alone. If these, however, contained fossils, he might, in many cases, be essentially aided in his endeavour to ascertain his whereabouts by their study; for although there is a wonderful resemblance, in not a few instances, between the extinct faunas of different regions, this resemblance rarely amounts to identity. Moreover, such an investigation of the fossil forms of any district necessarily presupposes search beneath the surface, while our object, at the present time, is only to consider what is above it.

The flora of any region is, or might be, to the botanist who was thoroughly familiar with the vegetation of the entire earth, almost an infallible guide in such a case as has here been presupposed.

We might imagine a person to have made himself so well acquainted, by study in the herbarium alone, with the different plants growing over the earth's surface, that he would, in a general way, if set down anywhere on it, give a very good guess as to his whereabouts. No geologist, however, would succeed in doing this, or in making any approach to it, from a study of the rocks alone, no matter how minute his preparatory studies might have been. Nor would the simple topographer fare better in this respect, for surface forms and contours repeat themselves indefinitely; and although it is true that in no two places they are exactly alike, yet there is no such method and harmony in the grouping of topographic details that any particular form could be assigned to any particular region. The inference from this is, that however important form of surface may be, as giving character to the scenery, yet the vegetation with which that surface is clothed is really the most essential feature in the complex of ideas which goes to make up what we call the landscape.

It is of one particular form of surface, and of the vegetation which is more or less peculiar to that form, to which the reader's attention is to be called at the present time. The more nearly level portions of the earth, and the kind of flora which these exhibit in various countries, are to be studied for the purpose of finding where they are situated, what has been their origin, and how their topographical features and climatological conditions are connected, in a general way, with the character of the vegetation with which they are clothed.

We have not far to look before discovering that comparatively level regions, distinguished by peculiarities of vegetable growth, are of common and wide-spread occurrence over the various land-masses of the earth. It appears also that a number of terms designating these peculiar areas are in general use, and that there is no sharp line to be drawn between them. To a certain extent, however, we do use, in speaking of these level areas, the same term which the people themselves employ who live in the region we mean to designate. Thus we speak of the steppes of Asia, the pampas of Central South America, or the llanos of the northern portion of the same country, because the inhabitants of those regions themselves use those words as indicating the peculiar features of the surface in question. Yet some of these terms, especially the word *steppe*, which is the German modification of the Russian word *step*,* is frequently applied to other regions than that of Northern and Western Asia, where it properly belongs. Thus we often read, in works of physical geography, of the steppes of Western North America, while some of the terms which belong to this category are applied quite vaguely, and somewhat differently, by different writers. It will be well, therefore, to pass in rapid review the more important level areas of the world which have certain features of vegetation in common, and to indicate their peculiarities, giving the names by which these areas are known to the inhabitants, and endeavouring to show what combination of conditions is indicated, in each case, by the name in question, and how far such terms may with propriety be used in other regions of generally similar character.

* German, *die Steppe.*

We may, however, in the first place, allude to what may be called the essential feature—especially from the botanical point of view—of the areas in question, namely, the entire, or almost entire, absence of trees upon them. This is the important fact which the observer, or the physical geographer, has in mind when speaking of steppe or pampa. But it must be borne in mind that absence of arboreal vegetation does not, by any means, necessarily imply absence of all vegetation, or even that other forms of vegetable life than those of forest trees may not be present in abundance and in great variety.

We may begin our studies with the steppes of Asia, since these are the grandest of all in extent, and perhaps the most varied in character; for not only are the vast areas of that nearly level and treeless country, which lie along the northern and northwestern side of all the great central elevated mass of that continent, commonly designated as steppe, but a large part of that central region itself is described under that name by recent eminent geographical authorities, so that we may include in the various forms of steppe existing in Russia and Central Asia the grass-covered plains of the lower regions and the almost entirely barren valleys lying between the various mountain ranges which are piled up over so large a portion of High Asia. Absence of trees is the essential feature in both the "steppe" and the "high steppe," as these regions have been, and may perhaps with propriety be designated; but the lower regions are in large part well covered with grass, and suitable for occupation by a pastoral people, dependent chiefly for the means of sustenance on their flocks and herds, while the higher valleys are almost uninhabitable, very sparsely covered with a shrubby vegetation,

and both too cold and too dry to offer any attractions except to the adventurous geographical explorer, who has still much to accomplish on the great central plateau of High Asia before its topography and natural history will have been anything like satisfactorily made out, even in their most general features. The vastness of the area which may be designated as steppe on the Asiatic continent is almost overwhelming. Nearly half of the 18,000,000 square miles which Asia covers is essentially a treeless region, and perhaps a half of that half belongs to the high steppe division, in which cold and dryness are the predominant characteristics.

From the fact that the steppes of Russian Asia have been longer known and more written about than any others in the world, the term steppe has been most ordinarily applied to similar areas in other countries. This is especially the case because such a use of the word has been sanctioned by Humboldt, who was the first to draw popular attention to this variety of surface as a feature of importance in physical geography.

In North America, where the treeless regions occupy so large an area, and where many of the physical conditions so closely resemble those prevailing on the Asiatic continent, the use of the term steppe has never been introduced among the people. Here, in fact, the character of the surface and distribution of vegetation over it, as well as its climatological peculiarities, have all been more satisfactorily and fully made out than in Asia, in spite of the fact that the latter country has been so much longer an object of scientific study. We may therefore dwell somewhat more at length on the treeless regions of the American continent than we have done on those of the Old World.

As in the case of the Asiatic High Plateau, so in North America, we have an elevated region of great extent, intersected by numerous mountain ranges rising much above the general level of the plateau itself. In Asia this high region is centrally situated with reference to the continental mass; but in North America it occupies the western side of the continent, and on the Pacific side descends suddenly and rapidly to the ocean level. In approaching this high, mountainous division of the continent from the east, the traveller passes over a surface which appears to the eye to be almost everywhere level and unbroken, but which really rises with a very gentle but gradually increasing slope to the base of the Rocky Mountains, where the elevation is nearly a mile above the sea-level. This gently-sloping belt has a width of more than five hundred miles, and extends from Mexico north through the whole continent to the Arctic Ocean. It forms the region universally known in the United States as "the Plains" (Fig. 2). It is an area nearly destitute of trees, but covered with a growth of various grasses, dense and abundant in the lower regions, and gradually becoming less so as we rise in altitude, but nowhere absent altogether. The trees, chiefly of the poplar family, and familiarly known as "cottonwoods," are hardly found at all, except along the edges of the streams, and they become less and less abundant as we proceed westward. This is the region so extensively ranged over by herds of "buffalo" (*Bison Americanus*), which not long ago existed in almost countless numbers, but which are fast disappearing as the country becomes more and more invaded by railroads, carrying hunters who seem bent on exterminating every kind of game which presents itself.

Beyond the Rocky Mountains, and between that range and the Sierra Nevada, is a belt of country in the central part of the territory of the United States which is more than a thousand miles in width, a large portion of which is without drainage to the sea, and is known as "the Great Basin." From the predominance over much of its surface of a shrubby plant familiarly called "sage-brush"—a species of *Artemisia*, or wormwood—the region is frequently designated by its inhabitants as the "sage-brush country" (Fig. 3). The valleys of the Great Basin are not suited for pasturage, except to a very limited extent. "Bunch-grasses,"* of which *Poa tenuifolia* is one of the most abundant and valuable, are sparsely scattered over the lower hill-sides, and along the river banks there is often a coarse growth of sedge-grasses, with a few cottonwoods and shrubby willows. The sage-brush country as it continues to the south-west, towards Mexican territory, becomes more and more occupied with various forms of the *Cactus* family, some of which have the altitude of trees, and give rise to the most curious type of landscape (Figs. 1, 5).

Between the Rocky Mountains and the Great Basin there is, included within the parallels of 36° and 44°, and lying chiefly in the states or territories of Colorado, Wyoming, and Utah, a broad belt of country greatly diversified by mountain ranges, and very dry and forbidding, although having a drainage to the sea. A large part of this region is underlain

* This term is applied to many grasses. The species noted in British Columbia and the neighbouring parts of Washington territory for its fattening qualities is *Elymus condensatus*.

by fresh-water Tertiary deposits, and belongs to the type of country known throughout the Far West as the "Mauvaises Terres," or "Bad Lands" (Fig. 4). The typical Bad Lands are, however, on the eastern side of the Rocky Mountains, and are largely developed along the various branches running into the Missouri River from the south-west, within the limits of the territory of Dakota. The Tertiary rocks of the Bad Lands are soft and permeable to water; and, being very easily eroded away, they have been worn into forms of the most striking and even picturesque character, although the general aspect of these regions is one of utter sterility, a condition resulting partly from the nature of the rock formations, and partly from the general extreme dryness of the climate.

Immediately upon the very backbone of the country, within the area occupied by the ranges properly designated as the Rocky Mountains, there are several broad and nearly level tracts, formerly the beds of lakes, which have become dry during later Tertiary times, and which are almost entirely destitute of arboreal vegetation. These areas have been long known as "the Parks," a name peculiar to this region, and which seems to have had its origin in the fancy of the early hunters, by whom also the smaller treeless plains, scattered here and there through the mountains, are designated as "Holes."

Between the sage-brush-covered valleys of the Great Basin rise numerous ranges of mountains, on the summits of which snow is usually to be found through the whole summer, lying in small patches in sheltered gorges, near the very highest points. None of these ranges rise high enough to have what may be properly called a line of perpetual snow. The lower slopes of these mountains are usually quite destitute of trees, which, however, make their appearance on the higher ranges as we rise toward their summits, the juniper and the one-leaved pine being the predominating species: the whole aspect of the vegetation, both of mountain and valley, being extremely monotonous, while the topographic features of the country are varied and even attractive from the brilliancy and beauty of the atmospheric effects, which are connected in their

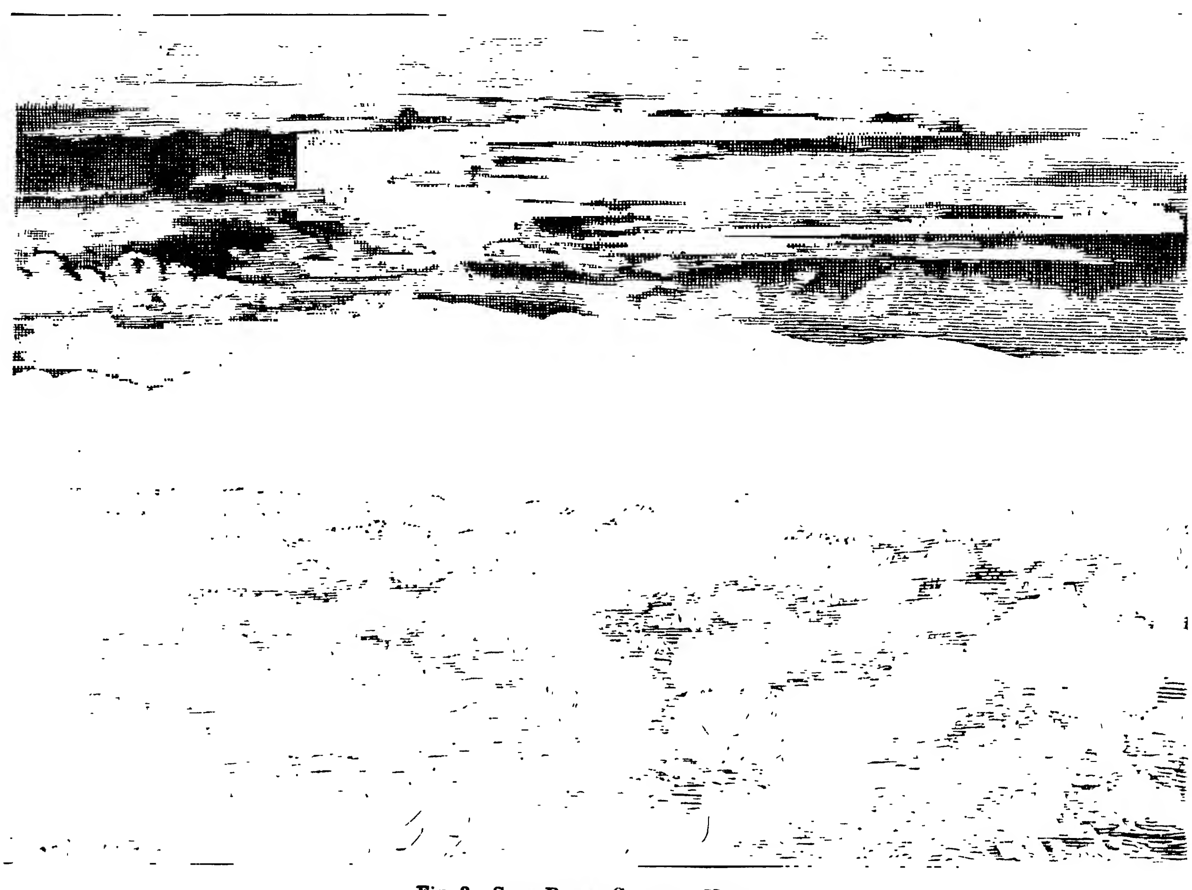


Fig. 3.—Sage-Brush Country, Nevada.

origin with the prevailing dryness, and which, at certain times, especially at sunrise and sunset, seem almost to glorify a region otherwise repellant in character.

Next to Asia and North America, the southern division of the New World demands our attention for the great extent of its level and treeless areas, so well known from the picturesque descriptions given by Humboldt. In point of fact, however, we understand less of the conditions in that part of the world than would be supposed, when the number of travellers who have visited it is taken into consideration. The absence of good maps, and of statistics of climate kept up for any considerable length of time, gives a very fragmentary character to most of the physical-geographical work which has been done in South America. In the absence of facts, theories have been promulgated which will hardly bear the test of examination.

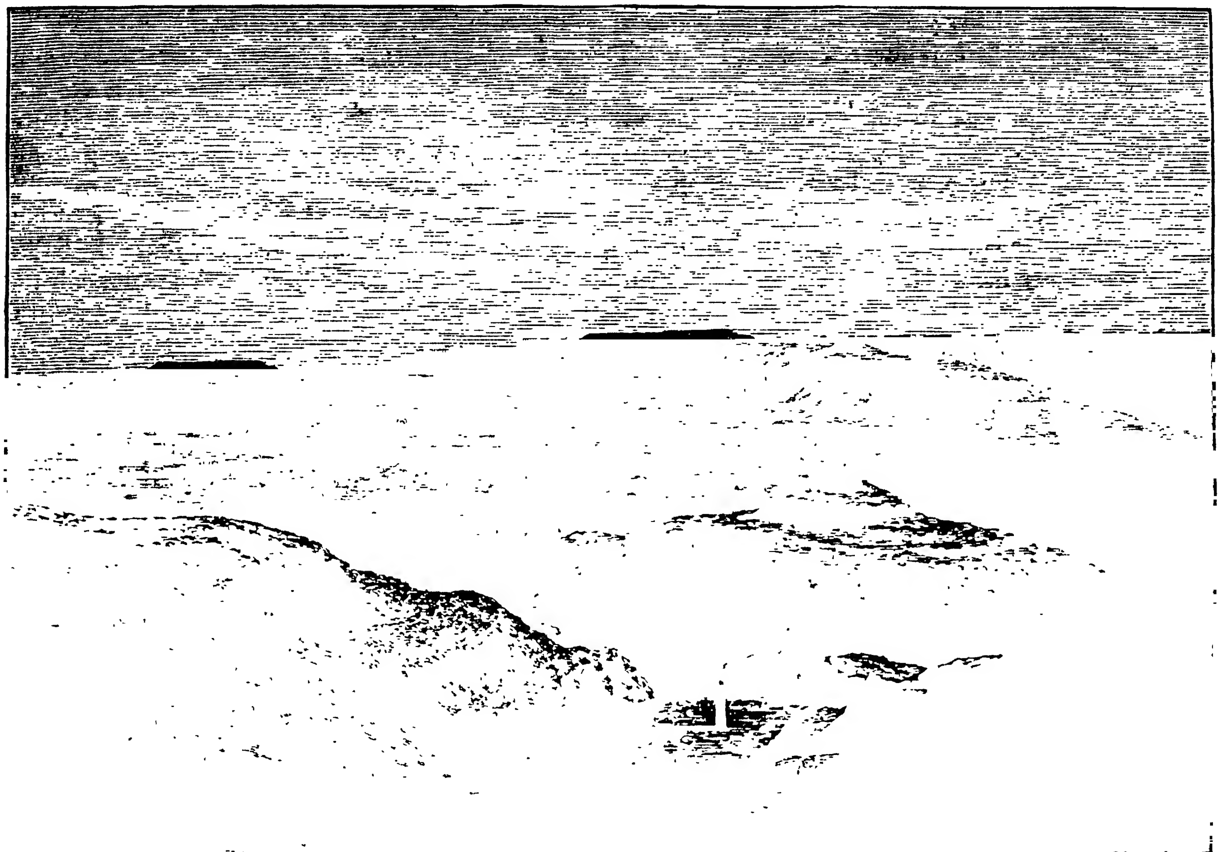


Fig. 4.—"Bad Lands," near Fort Bridger, United States.

The treeless areas of that country are known by various names. They are called "llanos" in the regions north of the equator, where they lie chiefly within the limits of Venezuela; in Brazil they are designated as "campos;" and as "pampas" in Peru, and especially in the central region lying between Brazil and Patagonia, and mostly included within the territory of the Argentine Confederation. The Spanish word "llano" is almost exactly the equivalent of the English "plain," the idea of flatness being the predominant one in both cases. "Campo" is the equivalent of the Latin "campus." But "pampa" appears to be a word which originated in some one of the South American aboriginal languages. It is applied in Peru to the regions of moving sand-dunes along the coast, but not to the treeless slopes of the Andes.

The llanos of South America are described by Humboldt as extending from the Caraccas coast chain to the forests of Guiana, and from the snowy mountains of Merida to the great delta formed by the Orinoco at its mouth, embracing an area of a quarter of a million of square miles. According to official determination, nearly two-thirds of Venezuela is "llano," or grassy plain, the prevailing vegetation belonging to the two orders of Cyperaceæ and Gramineæ. A large part of the surface

is described by Humboldt, as well as by Codazzi, by whom it was officially surveyed for the Government, as being extraordinarily flat; so much so, indeed, that over areas of several hundred square miles "no part seems to be a foot higher than the rest." The soil over large tracts is described as being absolutely destitute of even the smallest pebble. The region of the llanos is one of large rainfall, but the precipitation is very irregularly distributed through the year, it being entirely confined to the so-called rainy season. Humboldt describes with poetic fervour the awakening of the vegetation to renewed life under the influence of the welcome rain.

The pampas occupy a much larger area than the llanos, and are, as stated by recent travellers, of a considerably diversified character. The whole region commonly included within the designation of pampa by physical geographers, extends over more than a million of square miles. Some of this is grassy plain, well fitted for pastoral uses; a portion farther to the north, where dryness is a more predominant characteristic, is a barren waste, the soil being thoroughly impregnated with saline matter, evidently the bed of one or more former lakes. Flatness, absence of trees, abundant development of grasses in the moister portions, these are the characteristics of the region of the pampas, just as we have seen that they were of the steppe and the plains.

Before proceeding to a discussion of the causes of the peculiar condition of the surface indicated by the term steppe and the other nearly equivalent words, it may be noticed that it seems necessary that the two features of comparative flatness of surface and absence of trees should be present at the same time, in order to give rise to so marked a type of landscape as to call for a special name. There are large treeless areas on the slopes of mountains, although the occurrence is not a common one; but there is no special term by which such areas may be designated, and it is evident that they could not be included under any of the terms which have been mentioned. It must also be admitted that level tracts of country are much more likely to be barren of arboreal vegetation than are mountain slopes or regions with broken surface. For this fact there must be some reason, and we may now proceed to inquire what it is.

Before going any further, however, it will be well to notice in general what physical causes influence the character and development of vegetation. And it requires but a limited amount of observation before it will be clearly perceived that variations of temperature and in the quantity of moisture in the atmosphere have the most powerful influence on the flora of any region. In the case of temperature we see this almost equally well illustrated, whether we journey toward the Polar regions, or rise on the sides of lofty mountains, the decrease of temperature manifesting itself, in either case, in a most marked degree, by corresponding changes in the vegetation. The forest trees which are recognised as typical of warm climates disappear; those characteristic of colder regions make their appearance: these become more sparsely distributed, and dwarfed in size, and finally give out altogether; some grasses and flowering plants maintain their hold up to still higher and colder latitudes; and finally all these disappear, and only the lichens remain, of which no land, however far north it may lie, has ever been found entirely destitute. Of a similar character is the decline of vegetation as we ascend the slopes of high mountains. Trees finally disappear; grasses and flowering plants higher up do the same, and the lichens maintain their hold to the last, and often until the line of eternal snow is reached. That these effects are mainly due to temperature changes seems altogether probable, since there is abundant evidence that differences in the distribution of moisture are not here to be considered as the efficient agent in the matter.

That the presence or absence of moisture has a great influence in determining the character of vegetation cannot be denied; and that the distribution of forests over the earth's surface is largely connected with the amount of rain-fall in different regions, is beyond a doubt. An inspection of a rain-chart of the earth, and a comparison of the position of the rainless and drier areas with that of the belts or tracts destitute of trees, will be sufficient to show at once that, in a general way, regions where the rain-fall is deficient are those where trees are least developed; and also that a vigorous growth of grasses may be found where the precipitation is quite moderate in amount.

That the desert regions of the world are the rainless ones cannot for a moment be doubted. Absolute deserts, however, if by the term desert is meant a region entirely destitute of vegetation, are not by any means of frequent occurrence; and when such tracts do occur they rarely extend over large areas. The amount of desert on the earth is exceedingly small when compared with that of the region to which the name steppe may properly be

applied. Moving sands form the surface least favourable to vegetation; for even a rock surface entirely destitute of soil may be more or less encrusted with lichens. Hence the fact that a considerable portion of the Sahara is underlain with a sandstone which easily disintegrates on weathering, giving rise to great masses of pure sand, is regarded as one of the reasons for the utter barrenness of such large areas in Northern Africa.

Since moisture is essential to the vigorous growth of trees, so that very dry regions are, as a general rule, not covered with forests, it will not be difficult to understand why treeless areas are usually found in the interior of continental masses, as is so well illustrated by the position of the plains of North America, and that of the pampas and llanos of the southern division of the New World. The edges of the continents are the regions where the larger portion of the rainfall on the land takes place. To this rule there are but few exceptions; the most striking one is the existence of a rainless belt along a considerable part of the west coast of South America, a condition of things depending on the position of the chain of the Andes in that region with reference to the trade-winds.

But it is now necessary to proceed one step farther, and show how it is that level areas are so apt to be treeless, and thus to account for the coexistence, in so many cases, of flatness of surface and absence of arboreal vegetation.

To explain this, it will be necessary to allude to another feature of the North American landscape, not yet mentioned, about which much has been written, and but little correctly stated. Writers thus far have, almost without exception, confounded the prairies with the plains in discussing the physical geography of that continent. In point of fact, however, there is a very great difference between the two. The word *prairie* was originally introduced and used in describing the geography of the valley of the Mississippi by French travellers and missionaries. Hennepin, writing about 1680, describes the prairies of Illinois, and defines them with care and accuracy. The word itself, as used in France, is almost exactly the equivalent of the English "meadow," meaning a level area covered with grass. It is a term now current in the United States only as applied to the treeless tracts in the immediate vicinity of the Mississippi River, and lying chiefly within the boundaries of the States of Wisconsin, Illinois, Iowa, Missouri, and Arkansas. The prairies in these States are areas covered with a vigorous growth of various grasses, interspersed with numerous flowering plants, but destitute of trees. All through the prairie regions, however, there are tracts covered with a dense growth of "timber," as forests are universally called in the United States. This timber seems, at first sight, to be quite arbitrarily arranged with reference to the treeless areas. Sometimes the trees occupy large tracts on the higher portions of the country; at other times, and indeed much more generally, they line the sides of the "bluffs," which extend along the river courses, although not in close proximity to them. These bluffs are the steeper transitional areas between the nearly level or gently undulating uplands, which form the larger part of the surface of the country all through the prairie regions, and the "river bottoms," or quite flat land bordering the streams. Although the relative position of the tracts occupied by timber and grass may seem quite arbitrary, such is not by any means the case. The reason of this distribution becomes evident enough when one examines with care the character of the soil of the region. The trees are invariably found to be growing on the gravelly or coarser varieties of soil, while that which underlays the prairies themselves is exceedingly fine—so much so, indeed, that it polishes the implements which are used in its cultivation instead of scratching them. This extremely fine soil, which is, beyond a doubt, unfavourable to the growth of trees, is in places the result of the filling up of old lake-basins with fine sediment; but, in the true prairie region, more often the residuum left after the dissolving away of the soft, easily decomposed rocks which underlay the whole region in nearly horizontal beds. This residuum, which is almost impalpably fine, seems to have been swept into the basin in which the rocks were being deposited by marine currents coming from a great distance, and therefore bringing only the most finely comminuted material.

On some lines of railroad running west from Chicago, on which cuts of a few feet in depth are quite frequent, so that the character of the soil can be easily recognised, and especially within the first few years after the building of the roads, the varying character of the vegetation, as one passed from timbered to grass-covered areas, could easily be recognised, in almost every instance, as being accompanied by a corresponding change in the texture of the soil. In a great majority of cases one might tell by simple feeling of the soil, with the eyes shut, whether the surface was occupied by forest or by prairie.

The peculiar position of the prairie belt with reference to the treeless region a little farther west, where, beyond question, absence of sufficient moisture is the prime cause of the giving out of the trees, has naturally led physical geographers, not fully acquainted with the facts, to assert positively that the prairies are but the beginning of the plains, and that the origin of both was due to the same cause. A less reasonable theory even than this has been and is still frequently advocated by residents of the prairie region, as well as by others, namely, that the prairies are the result of the burning over of the surface by the aboriginal inhabitants. This theory is entirely opposed to all the facts, and it is quite unnecessary to occupy space in refuting it.

Fig. 5.—Cactus Country, Arizona. (*After Schott.*)

The meteorological records which have been kept for a considerable term of years at numerous stations in the prairie region, chiefly under the direction of the Smithsonian Institution, authorise the assertion, with no possibility of any contradiction based on facts, that the prairies are not dependent for their existence on the absence of sufficient rainfall. On the contrary, the precipitation over some of the very best developed prairie areas is large, much larger, in fact, than it is over the principal portion of the forest-covered region of the Eastern States.

The theory advocated of late by some physical geographers, and especially by Peschel, for the absence of trees over extensive regions of the earth, is to the effect that it is not the want of a sufficient quantity of rain, taking the average for the whole year, but its unequal distribution at different seasons. In this way the attempt has been made to account for the existence of the North American prairies. The most careful examination of the rainfall statistics proves, however, that in the region in question there is no such irregularity of precipitation as this theory demands. The distribution, through the year, of the rainfall in the prairie States is in no respect different from what it is along the Atlantic border, where forests are of universal occurrence. Besides, it is a fatal objection to this theory, that there are regions most densely covered with forests, where the rainfall is as irregular as

possible, whether considered from the point of view of the annual average, or of the distribution by seasons. Thus in California, along the western slope of the Sierra Nevada, forests exist which can hardly be surpassed anywhere in the world in density and absolute size of the individual trees, and yet there the precipitation is almost entirely limited to two or three months of the year, hardly a drop of rain ever falling during the months from May to November.

It is a fact, therefore, that the character of the soil has a powerful influence on the growth and character of the vegetation, as well as temperature and moisture. Wherever, for any reason, the soil is of especially fine texture, there grasses will flourish in preference to forests, provided the rainfall be not entirely insufficient. Hence we see at once why plains are more likely than mountain slopes to be treeless. It is toward the plains that the finer materials, abraded by erosion and denuding agencies from the higher regions, are being constantly carried, as they have been in former geological ages. The broader the plain, the more likely it is that a considerable portion of it will be covered with fine detritus, whether this be of subaërial origin or deposited at the bottom of the sea.

WEATHER FORECASTS.

By W. Liscombe Dallas, Meteorological Office, Calcutta.

Every one knows, either from actual experience or from hearsay, how differently different animals are affected by forthcoming changes of weather; and even as much as 2,000 years ago, the numerous changes in their habits which animals exhibit on the approach of rain were codified by the Greek poet and philosopher, in a poem called "The Phenomena." The low flight of the swallow, the peculiar washing which the cat gives to the back of its ears, and the donkey's shaking of its ears when rain threatens, all prove that these creatures are each a species of natural barometer. Such indications, however, are of very little general utility. It is impossible to be always accompanied by these natural weather-guides, and it is remarkable that shepherds and sailors, whose power of foretelling the weather is often very remarkable, only possess that faculty within certain well-defined limits, and that so soon as they are transferred to another scene their forecasts generally prove utter failures. It thus becomes necessary—more particularly for the inhabitant of the city, who has no distant range of hills or expanse of open country to act as his guide—that another process should be discovered by means of which some indication may be given of approaching changes in the weather.

Subtracting, then, the above class, which may be called natural forecasts, and which are generally impracticable and, except locally, useless, the student of weather has three courses open to him, and as a result there exists the usual difference of opinion which accompanies that open condition of affairs.

The first and by far the easiest plan of gaining a previous acquaintance with the approaching seasons is, if only there be faith enough to believe in it, to buy one of the almanacks which are annually published in the autumn, and which give, day by day, the weather which will prevail during the coming year. These almanacks give no sort of announcement as to the part of the country to which they refer, so that it is not unfair to assume that the forecast applies equally to the north of Scotland and the south of England. Could anything be more absurd? Yet so great is the desire on the part of the public to have a forecast, so intimately is the weather bound up in the affairs of every class of the community, that a lucky hit will make an almanack's reputation, and send its sale up to tens of thousands. The most prominent of these almanacks is probably that called "Murphy's." It was, I believe, the first weather almanack published, and as such attracted universal attention—a distinction which its early success more than justified. All the newspapers of the time contained notices of it, and in a leading journal, of Oct. 23rd, 1836, it was remarked that "if the basis of his theory prove sound, and its principles be sanctioned by a more extended experience, it is not too much to say that the importance of the discovery is equal to that of longitude." However, at that period meteorological science was very vague, and hence this almanack was ushered in with considerable *éclat*. It appears that by some means Mr. Murphy had predicted, on Oct. 28th, 1836, that a tremendous storm of

wind and rain would occur on Nov. 13th. This prediction seems to have been completely fulfilled, and on the occasion of the second appearance of the almanack, the success of its January forecast of intense frost with a few days of changeable weather was brought into remarkable notice by the fact that at this time the Royal Exchange was burnt down, and the water which was used to extinguish the flames was frozen into an immense sheet as it flowed away. This standard of success was not, however, maintained. Encouraged by his first successes, Mr. Murphy rushed recklessly into the uncertainties of weather-prophesying, and of course soon lost the confidence which his first lucky hits had inspired. By 1840 failure was admitted, and a bitter complaint made by the meteorological seer of the falling off in his popularity. He himself affirmed that his predictions were founded on the variations in the height of the Nile.

The two remaining systems really deserve consideration, as they are founded on scientific facts deduced from well authenticated physical phenomena. These two are the forecasts sent over to this country by the *New York Herald* Weather Bureau, and the forecasts issued by the Meteorological Office of Great Britain. For the American forecasts the British public is indebted entirely to the enterprise of Mr. Gordon Bennett and the late Mr. Jerome Collins, of the *New York Herald*, who was lost in the *Jeannette* Arctic expedition.

The merits of this system of warning are very considerable, and the Americans had the good fortune to start with the prestige of a very remarkable success. On this account, many people now regard these warnings as little short of infallible. But any one who has taken trouble to verify them, or has not ignored all but the successful messages, will come to the conclusion that, like all the other forecasts that have been placed before the British public, there is still much to be desired.

Whatever may have been thought as to the earlier warnings—and it is indubitable that the opinions of the English Meteorological Office and of Mr. Bennett's staff as to the success of the forecasts of 1877 and 1878 differ very considerably—there seems no question that subsequently great improvement was manifested. There were, however, still some very notable failures, the weak point in the forecasts being plainly shown in the following examples. On October 25th, 1880, the newspapers in London published this message:—"A dangerous storm is crossing north of Lat. 45°; will arrive on British and Norwegian coasts, possibly affecting French coasts, between 27th and 29th, attended by south strong winds, veering to north-west gales, rain and snow, in north low temperatures following. Atlantic very stormy."

On Dec. 2nd, this message was telegraphed:—"A dangerous storm is crossing, and will probably arrive on British, Norwegian, and French coasts between 5th and 7th, preceded and attended by rain and snow in north; south-east backing to north-west gales. Atlantic very stormy north of Lat. 40°."

These two messages are in all important details identical. In both it is a dangerous storm, and the British, Norwegian, and French coasts are to be affected; while the first direction and ultimate veering of the wind are sufficiently similar to warrant the supposition that as nearly as possible the same weather is to be expected between the 27th and 29th October as between the 5th and 7th of December. Yet the published account of the weather on those two dates showed an entire difference throughout. The first warning was successful, the second a failure. Between the 5th and 7th a very severe depression did pass across us, and fresh to strong gales were experienced on most coasts; while on the occasion of the second warning, no wind stronger than 7 (or slight gale) was reported all round our coasts. Now, in the latter case a seaman, guided by this warning, would have been kept in port at least two whole days, and have been obliged finally to sail without even the satisfaction of knowing that, though he had lost time, he had escaped a danger. This brings us to one of the principal demerits of the system, viz., the uncertainty as to the actual date of arrival—an uncertainty which tended to prevent these warnings from being of real practical use to the coasting-sailor, who, perhaps, with only a voyage of about a couple of hundred miles before him, and who, even if he were convinced that a storm would surely follow the warning, would, in nine cases out of ten, trust to its being in the latter half of the period warned, and chance arriving at his destination before the storm could break. In addition to this, there was another uncertainty which came out very strongly when carefully discussing these warnings, namely, as to the direction of the wind. In the case quoted above, that of Oct. 27th, and which was credited to the Americans as a success, hard easterly gales were experienced, while the south and south-west winds were not very strong, and the north-west gales were conspicuous by their absence.

The merits of the system are, however, great, and may be briefly summed up, as follows:—Previous warning, sometimes as many as four or five days beforehand, with general knowledge of intensity.

Its demerits are:—Uncertainty as to the exact date of arrival, direction of wind, and exact position of arrival of disturbance.

These merits and demerits are both explicable by the method of obtaining the information on which the warnings are based. It appears that steamers passing from this country to America have been supplied with forms on which to fill up the dates of the passage of barometric minima, and of gales or hurricanes. These facts being known, the rates of progress of such storms as are likely to touch the shores of Western Europe are calculated, and the warning is telegraphed over to Europe. It will readily be understood that from this necessarily meagre information it must be exceedingly difficult to obtain those exact particulars which are at present so much needed, more especially when it is borne in mind that it is by no means exceptional for a storm to exhaust itself within the limits of the Atlantic, and never reach our coasts at all. This fact explains many of the so-called failures.

The Meteorological Office forecasts are identical with the foregoing, in so far as they both regard cyclonic and anticyclonic action as the basis of all weather changes. The general impression that the wind blew in a broad band all over the country held its ground firmly until a comparatively recent date, and it was not until a number of observations were taken, on the occasion of the passage of some large storms, that it was discovered that a westerly gale might be blowing in the south of England and an easterly gale over Scotland. Further investigations showed that in our hemisphere this relation of the wind was always observable. Thus, if a storm were to pass from west to east across Ireland and north England, westerly gales would blow in the south, southerly gales in the east, easterly gales in the north, and northerly gales in the west. In addition to this vorticose circulation of the wind, the same observations showed that the weather varied nearly as regularly as the wind; places bearing a certain relation to the position and course of one storm, experiencing, on the average, the same weather with each successive storm travelling in the same direction and having the same velocity and intensity.

In a former paper * the characteristics of and differences between the cyclone and anticyclone were fully explained, and it is sufficient here to say that the former produces generally foul and the latter fair weather. The following are the principles on which the forecasts are issued:—It is necessary to find out under which condition the district lies, to carefully note the position of the anticyclone, whether the readings of the barometer within it are relatively high or low, and whether the anticyclone is comparatively firmly established and stationary. If we were to find a large anticyclone lying over France and extending well northward, say over Ireland and the greater part of England, it would in nine cases out of ten be safe to forecast that light south to west winds would prevail over those countries, with fair, dry weather; but remembering how cyclones circulate round from west to east on the northern side of an area of high pressure, westerly gales and rain would be expected in the north of Scotland and over Norway. Again, when the anticyclone lies farther to the southward, and at the same time a little to the eastward, of the position noticed above, the depressions pass from south-west to north-east, and south-westerly winds with mild rainy weather prevail, especially in the west and north; and the frequency of this distribution of pressure is exemplified by the mild, moist climate of the western and northern districts of the United Kingdom. Such is the bare outline of the system on which the forecasts are based; but in dealing with each day as it approaches, small irregularities, intricacies, and modifications are disclosed, which, not affecting much the weather for the year, render diurnal and district forecasts uncertain in the extreme. An example of this uncertainty was given during the winter of 1880–1. In the early part of the season an area of high pressure, or anticyclone, advanced from the southward over the British Isles. Now, it has always been a dictum in modern meteorology that an anticyclone gives us in winter cold, frosty, foggy weather, yet on this occasion the weather was decidedly mild, and very little fog prevailed. Later on, a change occurred. A depression passed down over us from the northward, and was followed by an area of high pressure, which also had its origin in the more northern parts of Europe. This anticyclone, though for some time not so marked as the one noticed above, yet brought the exceedingly severe cold which prevailed during January, 1881. It therefore appears that it is not sufficient to be aware that an anticyclone lies over a certain district in order to forecast its weather, but it is necessary to know the direction

* "Weather Telegraphy:" "Science for All," Vol. II., p. 367.

whence the area approached; the first-mentioned anticyclone having apparently continued, even when over us, to draw its supply of air from the warmer southern latitudes, while the second brought with it the intense cold of its northern birthplace.

Opinions as to the success of the forecasting system are confusing and contradictory. The official checking gives about seventy-five per cent. of success; but it is probable that were the forecasts checked having regard to only one place and not as a district, the percentage would be considerably less. When it is possible actually to connect a place with either the cyclone or the anticyclone, it may with more or less safety be predicted that the weather will be dry or wet according to the dominant system; but in addition to the doubt as to the course the cyclone will travel, there is a large neutral ground in which the two systems fight for the mastery, and dim uncertainty prevails.

It must be evident to any one who has at any time studied the distribution of atmospheric pressure, and who consequently must be aware of the frequency with which the anticyclone is located in the south, and that in consequence the normal passage of depressions is from west to east, that our utter isolation on our western coasts is an almost impenetrable barrier to all attempts at long-period forecasting. To the westward of Valentia stretches the Atlantic Ocean, and no appliances at present invented will give us any idea of what is in progress 500 miles from our shores—a distance which a moderately quickly-travelling depression would accomplish in twelve hours. It is on this account that the efforts of the Americans deserve so much commendation. It is an effort to explore the "dark continent" of storms, though meantime we can only regret that its failure in respect to direction of wind and actual date of arrival is unavoidable. In the case already quoted as a success, the wind was almost due east, so that a ship leaving Hull for the Baltic, instead of sailing into a south-west gale, which would be comparatively favourable, would have encountered a hard easterly gale, and be driven back on a lee coast. On the 27th the Meteorological Office sent out an order to hoist the north cone for an east to north-east gale, so that the British office may claim to have known much more as to the direction of the storm and the wind; but unfortunately the warning was only issued on the 27th, and the storm broke on the 28th, so that the Americans had two clear days' start. It is plain that in some amalgamation of the two plans lies the greatest chance of success, and one of the first things to be done is to open up the North Atlantic. Mr. Symons and other writers have advocated the drawing of Atlantic charts, and as observations are being daily collected, it may be hoped that in time the inhabitants of the British Isles will have the sea in their neighbourhood investigated with the minuteness and care which the importance of the subject deserves.*

THE PLANET MERCURY.

By W. F. Denning, F.R.A.S.

Of all the known planetary members of the solar system, Mercury is the nearest to the sun, and there is considerable difficulty in observing him in consequence. He is always more or less immersed in the solar rays, and his dimensions are extremely small, so that circumstances combine to render him a somewhat unattractive object, and one seldom coming within the reach of casual observers.

The discovery of so small a planet, and one in connection with which the conditions are so directly opposed to successful observation, reflects much credit upon the ancient astronomers, who, after they had detected Venus, Jupiter, Mars and Saturn, must have had no small trouble in distinguishing Mercury. But no ancient records exist as to the facts of the discovery, so that we cannot form any idea how long this planet eluded detection, or whether it was found simultaneously with the brighter planets of the series. Even the name of the discoverer has not been preserved. Venus and Jupiter would be certain, in the most primitive ages, to attract immediate notice as stars of special type. Their surpassing brilliancy and proper motion in the heavens would cause them to be singled out as of distinct character to the host of stars presented in the firmament. Mars and Saturn must also have been noticed as bodies of similar nature, after which the nocturnal sky was probably

* See also "Weather Signs and Weather Changes:" "Science for All," Vol. V., p. 84, and "High Clouds and Moonshine:" Vol. V., p. 105.

scanned in vain for new orbs during many ensuing years. No other bodies belonging to the class of "wandering stars" could be found, though the relative positions of most of the visible stars were roughly noted, and afterwards compared with the idea of finding another of these singular objects. Amongst the multitude of stars, in their unique and infinite variety of grouping, only four bodies could at first be distinguished which by their motions and conspicuous aspect were proved to be of exceptional character.

But now a new system of observation may have been introduced, for it had been proved unavailing to search for another planet after darkness had fully set in, though this was naturally suggested as the time best adapted to the work. It was noticed that Venus never departed very far from the sun, and that, in fact, she was his constant attendant, allowed to recede away from him for a certain distance and then to rapidly approach him again. If, therefore, another planet existed whose motions were controlled similarly to those of Venus, such a planet would, if never travelling far from the sun, be best discerned in the morning or evening twilight above the place where the sun made his first or last appearance. An acute observer, reasoning thus, stations himself on a commanding position, whence he may obtain an uninterrupted view of the horizon, and here he begins a systematic search for new planets. Before sunrise he is there looking eastwards, and marking down the positions of the chief stars visible at low altitudes. After sunset his gaze is directed westwards, and the same method adopted. For a long time the process is repeated. Not a single opportunity is neglected. Whenever the sky is clear and the twilight showing, the observer stands with unfailing persistency at his post. Though for a time the search is fruitless, yet the feeling of expectation and possible success encourages him to renewed effort, and he determines not to relinquish the task he has imposed upon himself until fully persuaded that it cannot yield the coveted prize.

One night he returns to his work with a sense of despondency, and a conviction that it is hopeless. The sky is remarkably clear as he begins, in his accustomed way, to note what stars are perceptible upon the horizon. Suddenly his eye catches a glimpse of an object which he feels certain could not have been visible on the few preceding nights. His enthusiasm is fully aroused. There is no fixed star in the position he has assigned to the new object, and he awaits, how impatiently and anxiously no one can tell, the next fine evening to verify his discovery. The intervening hours are counted, every passing cloud is watched, and ultimately, as the sun falls to the horizon, our observer takes up his place at a much earlier hour than usual. How the sun seems to lag that night before his setting: how slowly the sky begins to darken after his last rays have disappeared! The observer's eye is eagerly directed towards the point in which the strange star of the previous night was situated, and there, a little to the westward, it is seen again, and with greater plainness than before. Every doubt is now dispelled. This is the object for which he has been waiting so long. His oft-repeated vigils have been rewarded by the detection of another orb belonging to the order of "wandering stars."

No further discoveries of planets were made until the beginning of the seventeenth century, when the invention of the telescope effected a revolution in observational astronomy.

Mercury was found to be a very small planet, though the accurate determination of its real diameter was left to the instruments of modern times. Compared with Jupiter and Saturn, this planet is, in fact, a most diminutive orb, as shown in the following diagram (Fig. 1):—

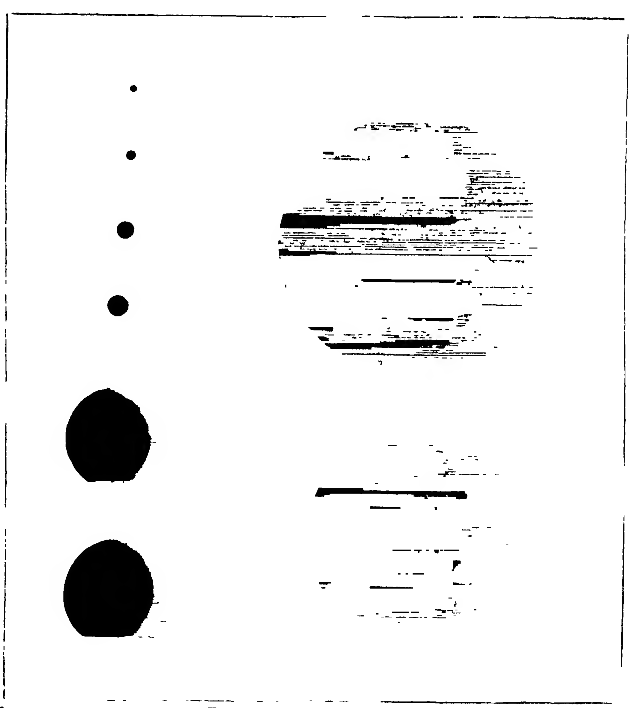


Fig. 1.—Relative Dimensions of Mercury and the other Primary Planets.

It is situated at a mean distance from the sun of about thirty-five millions of miles, and completes a revolution in eighty-eight days. Its apparent diameter varies considerably, according to position. When the planet is nearest to the earth, at inferior conjunction, the disc may subtend an angle of 13 seconds of arc; but at superior conjunction this amounts to no more than $4\frac{1}{2}$ seconds. When Mercury is situated at that point of its orbit apparently most distant from the sun, it is said to reach its greatest elongation, and at such a time is occasionally visible as a morning or evening star, according as its position is west or east of the sun. But even under the most favourable conditions it is not above the horizon for a longer period than about two hours in the absence of the sun, and the distance separating the two bodies never exceeds 29°.

This planet has, therefore, received very little attention from observers. Its small proportions and constant proximity to the sun render it a very uninteresting object; hence it is seldom examined in powerful telescopes, so that we have little evidence as to what special features are presented on its disc. It is, however, questionable whether any such details could be distinguished even were the perfected appliances of modern times directed to such a purpose. The smallness of the object and the constant "glare" attending it must obviously prevent good definition, and entirely obliterate any faint markings on the disc, so that we cannot wonder at the negative results which have hitherto attended such observations. Even in the case of Venus, which is a much larger planet, and far better situated than Mercury, the results are of very meagre and doubtful character, and go far to prove that its markings are of the faintest possible description, and only to be glimpsed in instruments of the first excellence.

But in regard to observations of Mercury, the evidence does not absolutely negative the existence of visible markings upon its surface. Indeed, it is occasionally recorded that faint spots of uncertain character have been distinguished. On June 11, 1867, a spot, with minute lines diverging from it N.E. and S., was noted a little to the south of the planet's centre, and on March 13, 1870, a large white spot appeared near the east limb; but these seem to have been exceptional, and we have no prolonged series of such observations by some experienced telescopist which would, no doubt, throw considerable light upon the character of these markings, and not only furnish us with the means of computing the rotation period of Mercury, but possibly give us a clearer insight as to the phenomena occurring on its surface; and such data would be of special value in inquiries connected with the physical condition of the planet, and give rise to some interesting speculations as to the envelope in which it is presumably surrounded, and the variations manifested in it. We would therefore point out to observers the desirability of entering diligently upon a critical and frequent review of this planet, with the purpose of obtaining such materials as will conduce to further our knowledge of the configuration of its surface.

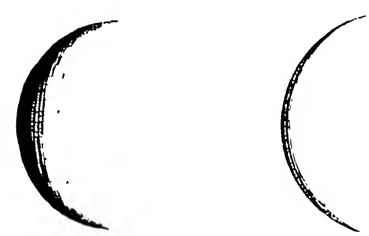


Fig. 2.—Mercury as a Crescent.

Early in the present century Schröter and Harding, at Lilienthal, made a number of observations of the planet, and obtained results indicating that the surface was of mountainous character. The south horn (Fig. 2) sometimes appeared blunted, and minute prominences were traced upon its edge. Other irregularities were observed with sufficient distinctness to warrant the inference that the elevations must reach a height of eleven miles perpendicular, and that the axial rotation was performed in 24 hours, 5 minutes, 30 seconds. Bessel also computed the latter element from five observations of Schröter during a period of fourteen months, and found 24 hours 53 seconds, which was afterwards confirmed. These appear to have been the only good determinations ever made of the rotation of Mercury, notwithstanding the fact that there are now a vast number of telescopes and observers adequate to the work. It is to be hoped that more attention will be directed to this planet in future years, and that its visible aspect will be sedulously investigated with competent means.

Certainly the most interesting detail in the telescopic appearance of Mercury is afforded by the

phases of the planet. These were first distinguished by Hortensius in about the year 1630, and are visible in small instruments.

Both Mercury and Venus exhibit all the phases of the moon, their orbits being interior to that of the earth, and it is evident that these phenomena are the natural result of their varying positions relatively to the earth. The planets all shine by light reflected from the sun; hence it is obvious that when either Mercury or Venus occupies that part of its orbit nearly interposed between the sun and the earth—called inferior conjunction—it will be invisible, or visible only as a very narrow crescent, because its illuminated hemisphere is turned away from the earth. On the other hand, it is equally clear that when these planets are at the opposite points of their orbits, that is to say, nearly behind the sun—called superior conjunction—they will exhibit discs of circular form, inasmuch as the same hemisphere, and that illuminated, is presented to the sun and earth. But in the latter case, it is obvious that the apparent dimensions of these planets will be far less than when viewed as a crescent at inferior conjunction. In fact, their distance from the earth is greater by the diameter of their orbits, and this, in the case of Mercury, amounts to about 70,000 miles, and has the effect of enlarging the planet's apparent dimensions from 4½ seconds to 13 seconds as it traverses its path from superior to inferior conjunction. When situated about midway between these points, and nearest its greatest apparent elongation from the sun, it appears like the moon in her first or last quarters, and is visible either as an evening or morning star.

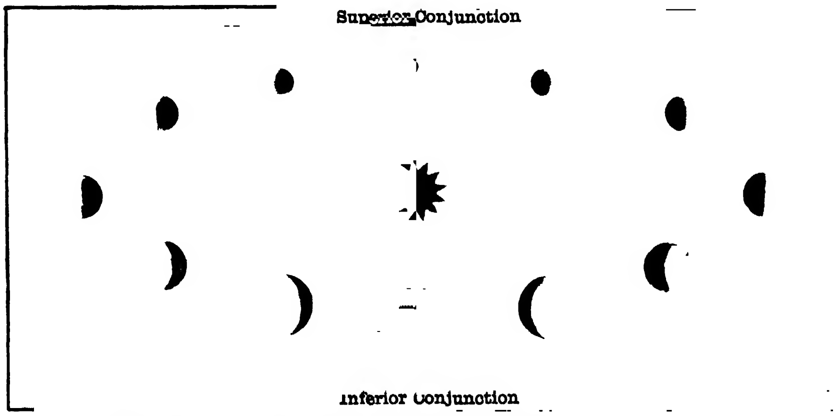


Fig. 3.—Phases of an Inferior Planet in Different Parts of the Orbit.

Results of observation have occasionally shown that the proportion of the enlightened hemisphere is less than that computed. Schröter, who paid marked attention both to Mercury and Venus, was the first to remark this, and his observations were subsequently confirmed by Beer and Mädler, who attempted to explain it on the theory of a dense atmosphere enfeebling the light at the terminator.

The following diagram (Fig. 3) shows the varying size and phase of an inferior planet in several positions of the orbit.

It occasionally happens that at inferior conjunction the planet is situated precisely between the sun and earth, and is then projected as a circular dark spot upon the sun. This phenomenon is termed a transit (Vol. IV., p. 300), and is sometimes witnessed with considerable interest. Gassendi, at Paris, appears to have been the first to observe an occurrence of this kind, namely, on November 7, 1631, and since his time they have been commonly observed whenever the circumstances were favourable. The duration averages about 4 hours, though a transit may extend over 7h. 18m., as on May 7, 1799, or be visible only for 1h. 14m., as on Nov. 12, 1782. The following is a complete list of the transits of Mercury during the present and ensuing century:—

Transits of Nineteenth Century.	Transits of Twentieth Century.
1802. November 9	1907. November 12
1815. November 12	1914. November 6
1822. November 5	1924. May 7
1832. May 5	1927. November 8
1835. November 7	1937. May 10
1845. May 8	1940. November 12
1848. November 9	1953. November 13
1861. November 12	1960. November 6
1868. November 5	1970. May 9
1878. May 6	1973. November 9
1881. November 8	1986. November 12
1891. May 9	1999. November 24
1894. November 10	

These transits invariably occur in the months of May or November, for the following reasons. The sun's apparent annual revolution around the earth carries him through every point of the ecliptic, and he must therefore necessarily intersect the orbit of Mercury at his ascending and descending nodes. The positions of these are in precisely opposite parts of the ecliptic; hence the sun crosses them at six months' intervals, that is, in May and November. In the case of Venus, the months are June

and December, and it is only at these special periods that transits can possibly occur. Transits of Venus are, as we have already seen, of far greater rarity and importance than those of Mercury.

Some curious phenomena have been observed in connection with transits of Mercury. One or two bright spots have been distinguished upon the opaque disc of the planet as it passes over the sun, and occasionally a luminous ring has been observed to encircle it, which some observers attribute to an atmosphere upon Mercury. But the evidence of different persons who have witnessed these transits, and applied powerful telescopic means to the detection of such phenomena as are visible during their progress, is very contradictory as regards details, so that even during one and the same transit the results are not often compatible. Some observers will notice the bright speck upon the opaque sphere of the planet, and express themselves confidently as to its existence; while others, at the same time provided with equally good eyes and instruments, fail to obtain the faintest glimpse of it, though close attention may have been directed to its detection. The weight of the evidence strongly inclines to the view that the bright spot is in reality visible, though not always seen with equal distinctness, and by all of the observers. Moreover, its position, as assigned by different estimations, is not always accordant, and there is a difficulty in reconciling the observations. During the transit of May 6, 1878, some interesting results* were obtained at Greenwich, where the weather appears to have been more favourable than in many parts of the country. Mr. Christie, observing with the great equatorial, aperture 12·8 inches, saw "a minute spot very near the centre of the planet's disc. It was slightly diffused, but with a brilliant, star-like nucleus. A bright halo of somewhat irregular outline, and having a breadth of 3″ or 4″ was seen round the planet, with an inner and much brighter ring about 1″ in breadth." Dr. Dunkin, using a 6-inch equatorial, says, "Mercury was intensely black, except that I saw distinctly a very minute point of light near the centre, a little towards the following limb of the planet. After an interval of two minutes it became more vividly distinct than before. During a few minutes of superb definition, the ring or corona of light around Mercury was clearly visible, its breadth being about one-third that of the planet." Captain Tupman, also with a 6-inch telescope, could not detect the slightest trace of a permanent white spot within the disc, nor any ring, either luminous or shadowy, surrounding the planet. He was struck with the extreme sharpness of the planet's outline. Mr. G. S. Criswick employed a similar instrument, and saw "a ring of light, equal in breadth to about two-thirds of the diameter of the planet, irregularly defined. Two bright spots were also seen on Mercury." Mr. Downing (6·7-inch equatorial) saw the bright ring, but no spot, on the planet, and Mr. W. C. Nash (6-inch equatorial) could not see either the luminous ring or spot (Fig. 4).

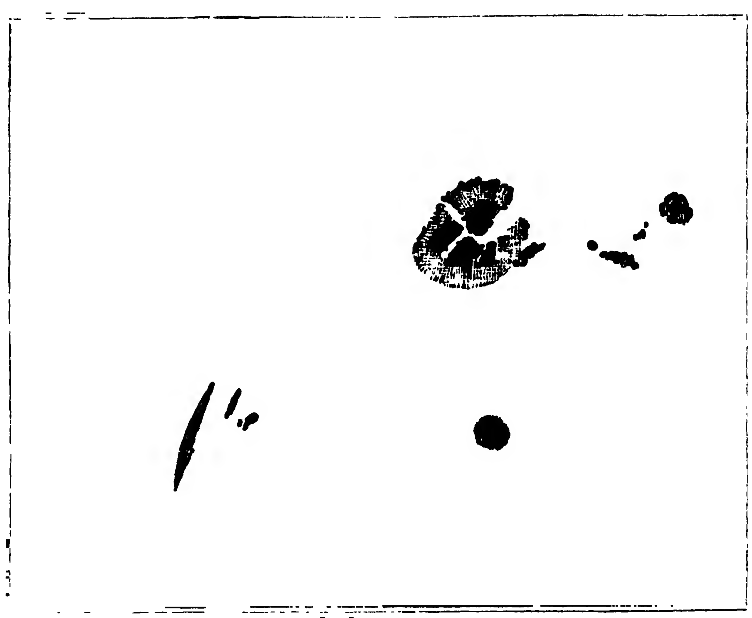


Fig. 4.—Mercury in Transit across the Sun.

The bright spot is, no doubt, a mere optical effect, and is seen under a variety of aspects, in different telescopes, and with different eye-pieces. The luminous ring, or aureola, of the planet, may also, in a great measure, receive a similar explanation, for no such appearances have ever been observed, except during transits, when the effect of the sun's "glare" must obviously bring out telescopic imperfections, and create luminous appearances which are entirely illusory; and, in connection with

* "Monthy Notices of the Royal Astronomical Society," May, 1878, which contain several important accounts of the transit. Comprehensive memoirs have also been published in L. Niesten's "Notices Astronomiques" (1880), and in the Washington Observations (1876), Appendix II.

this part of the subject, it should be borne in mind that our own atmosphere, through which all celestial phenomena have to be observed, may be held responsible for some of the anomalies revealed by observation. Moreover, there is the solar corona intervening between Mercury and the sun, which may possibly have a small share in producing the observed effects. In any case, the descriptions are very discordant as to details, and go far to prove that they are of mere optical character, and seen under different aspects, according to the instrument and power employed; and the manner in which an observer interprets and describes the features displayed before him seldom agrees in two cases, for in this, as in all other departments of astronomical observation, "personal equation" is liable to originate differences where none really exist.

Though Mercury is often described as an object seen with great difficulty and only on rare occasions, there is no doubt that a person who will make special efforts to see the planet will soon succeed in his endeavours. He should find the position of the planet by a reference to an almanack, and then, waiting his opportunity, scan the region with an opera-glass, or telescope of very low power. In this way Mercury may soon be detected, and when once found will be observed with less difficulty afterwards; indeed, at the most favourable epochs the planet may be readily recognised with the naked eye as it hangs over the horizon and shines with a white sparkling lustre, exceeding that of any fixed stars which may be in the same region.

In February, 1868, the planet was conspicuously and frequently visible in the evening sky, and its brightness appeared to rival that of Jupiter, situated only a few degrees distant. The writer also observed the planet after sunset on May 31, June 1, 2, 3, and 4, 1875, though the maximum elongation did not take place until June 10. In May, 1876, a further series of observations * was obtained at Bristol, and the weather being more than usually clear between the 5th and 28th of that month, the planet was detected with the naked eye on no less than thirteen nights. On the 13th it came within the range of vision at 8h. 20m., and continued perceptible until 1h. 20m.; on the 19th it was watched from 8h. 32m. to 9h. 55m., and the average duration of its visibility as a naked eye object was found to be about 1h. 20m. between the 10th and 20th. The planet grew rapidly fainter every night, though its apparent diameter had increased from 5″.8 on the 5th to 8″.8 on the 25th; in the meantime, however, the phase had decreased considerably, having dwindled from a gibbous form to that of a crescent, and had so much enfeebled its lustre as to render it nearly invisible, notwithstanding the decided increase in its diameter. In fact, the rapid loss of phase was not nearly compensated for by greater dimensions, and this fact should be always borne in mind by those who make such observations, for evidently the planet is most easily recognised a few evenings *preceding* its greatest eastern elongation, and a few mornings *after* its greatest western elongation. Many persons have made vain efforts to distinguish Mercury, owing to a lack of appreciation of all the conditions involved, and have been much disappointed in consequence; but the search cannot be futile if made at an opportune period as regards elongation and phase of the planet, and when the sky is sufficiently clear for the purpose.

As an evening star, the planet is best detected in the spring months, when its declination is north of the sun, and it remains above the horizon some two hours after sunset. In the autumnal months, Mercury may be equally well seen in the morning twilight, and indeed this is a very favourable season for viewing the planet telescopically, because it may be retained in the field of view until after sunrise, and this is important to those not provided with equatorially mounted instruments, and who have no other ready means of examining the planet in the daytime. It is very essential that it should be carefully inspected with the sun above the horizon, because it cannot otherwise be observed at a fair altitude, and it is a fact of common experience that a celestial object never presents a well-defined appearance near the horizon. The prevalence of mist and heated vapours, floating about at low altitudes, originates a tremulous or rippling aspect upon any object through which it is seen, and altogether destroys that sharp and serene appearance which it is always desirable to obtain. This will be acknowledged by any one who makes comparative observations of objects at high and low altitudes. He will not be long in discovering that, though to the naked eye a planet is sometimes very conspicuous just before setting, it presents in the telescope a very ill-defined and unsatisfactory appearance.

* "Monthly Notices of the Royal Astronomical Society," June, 1876.

THE MIGRATION OF MAMMALS AND FISHES.

By J. Duns, D.D., F.R.S.E.,

Professor of Natural Science, New College, Edinburgh.

THE title of this paper is familiar almost to commonplace. But the facts which it covers suggest some of the most difficult questions in natural history. In introducing my subject I fall back on the old Socratic method of questioning: What is migration, and what are the causes which regulate it? Are the climatal conditions of the localities which, for the time, animals leave, unfavourable to the health of the migrating species, and, if so, can we co-ordinate the unfavourable seasonal conditions in the one area with favourable seasonal conditions in the area they visit? Is the migratory habit the expression of instinct, innate and irresistible, or is it the result of slow secular growth within the lines of heredity? Is there a sense in which all animals may be said to migrate? If, as is granted, the range of certain genera was far wider in very early historic, or in pre-historic time, than that of their modern representatives, is there anything in the facts of their present geographical distribution fitted to explain this? Admitting man as a factor in determining the range of certain species at present, have we materials to gauge the influence of society in, say, pre-historic time on forms now extinct in areas where they once abounded? In putting the questions I have purposely avoided logical sequence. They are simply intended to suggest the chief aspects of a great subject, which may be conveniently illustrated under the heads periodic, seasonal, and partial migrations.

First, then, there are periodic migrations. The wandering referred to under this section has not been definitely timed. There are cases on record which show that six, eleven, thirteen, or eighteen years may elapse between one migration and another. I take the northern grey squirrel (*Sciurus migratorius*) as an illustrative instance of periodic migration. Met with as far north as Hudson's Bay, it occurs also in the New England States, in the State of New York, and in the mountains of Pennsylvania. Audubon and Bachman tell us that "The farmers in the Western wilds regard them with sensations which may be compared to the anxious apprehensions of the Eastern natives at the flight of the devouring locust." These observers twice met them on the march—in 1808 and in 1819. They congregate in different parts of the wide north-west, and set out in irregular troops, always in an easterly direction. Neither mountain, lake, nor broad rapid river turns them from their course. Waving woods, rich corn-fields, and carefully tended gardens are laid waste, where these intervene between them and the eastern forests. They thoroughly realise Joel's graphic description of another migratory form—"They march every one in his own ways, and they break not their ranks. The land is as the garden of Eden before them, and behind them a desolate wilderness."

The Lemming (*Myodes lemmus*) is the form most commonly referred to as an instance of periodic migration (Fig. 1). Olaus Wormius, Pontoppidan, Linnæus, Cuvier, and others, early directed attention to the peculiar migratory habit of this animal. Wormius says the plague occurs once or twice in the course of twenty years.* The account given by Linnæus is well known. He describes their headlong rush, the rectilinear parallel furrows made by them in the way, the havoc produced in vegetation, the rocks they climb, the lakes and rivers they swim, and their persistence in the same undeviating path. Later witnesses corroborate these statements, testifying to the prodigious numbers which take part in these migrations, though there is no proof that all do. While, then, bearing in mind that inferences carry with them the weight of the facts by which they are warranted, we may ask: To what are we to trace these periodic movements? Does food, or temperature, or breeding instinct determine the migration? Any value there is in the food theory lies in the ascription of a quality to these animals akin to forethought. A season of scarcity is seen to be on its way, and to avoid it the animals migrate. But this is seeking an explanation in a region outside of science. Van der Hoeven and others lay stress on temperature. But as the lemming leaves its usual habitat before the cold weather sets in, and especially as in the years they

* The monograph of Wormius on the lemming gave currency to the prevailing popular belief, that at such periods it literally rained lemmings: "Historia muris Norvegici, vel animalis quod e nubibus in Norvegia decidit, et sata ac gramina magno incolarum detrimento celerrime depascitur."

do not migrate they live through very severe winters, little weight can be given to this. Thus Sir George Nares's men met with lemmings in latitude 83° N., and Sir John Ross saw them at 81° 45′ N., sixty miles from Spitzbergen. Captain Feilden does not think they hibernate, but live on saxifrages and other plants under the snow. Indeed, we cannot conceive it possible that a hibernating animal could, in countless numbers, in this fashion cast itself free, at irregular intervals, from the laws which regulate hibernation. The breeding theory is as little satisfactory. Were there anything in this, the migration would be seasonally regular and not irregularly periodic. It is doubtful if the facts entitle us to formulate a definite opinion, and we may again only indicate the direction to which conviction tends by putting it in the form of questions. Is this periodic migration a natural provision for maintaining the balance of living forms? Does their rapid, prolific increase demand a check, and is this provided by these migrations; it being well known that few return to their usual habitats? Have we not analogous recent instances in the sudden appearance in France, England, and Scotland, of myriads of related forms (*Arvicola agrestis*)?

Next, there are seasonal migrations. Out of the numerous instances recorded, I take the reindeer (*Cervus tarandus*), because it is best known, and suggests more points of interest than any other form (Fig. 2). Its present geographical range is comparatively limited, but there is abundant proof that it was not so in very early times. Its migrations are two—one in May, towards the remote elevated northern plains, the other, or return journey, in September, to the forest regions. The chief authorities regarding the migratory habits of this magnificent deer are Von Wrangel,* Richardson,† and Nordenskjöld.‡ At the migratory season they congregate in thousands, and, separating into herds of two or three hundred, move forward in a mass sometimes from thirty to sixty miles broad. In Siberia they follow the same route year by year, refusing to be turned aside by dangers and obstacles of any sort. That they go north to avoid the heat with its accompanying insect plagues, and return to the forests in search of herbage there can be no doubt. But this sheds no light on their former wide geographical range—traces of them having been found in England, Scotland, Ireland, Belgium, and the south of France. The explanation of their present restricted range is most likely to be traced to the growth of population. But some curious facts on this point deserve notice. Not unseldom individuals are found much farther south than the general body. Assuming that the Caribou is only a variety of the European species, we have proof that the American reindeer wanders far beyond the limits of its old world representative: it even extends as far south as Maine.

Lastly, there are partial migrations, periodic and seasonal. In this case the movement is neither general nor wide. Individuals, and not great companies, take part in it; and its range is within a comparatively limited area. Indeed, migration in the sense in which the term is applied, say to birds, cannot be said to take place. Yet the changes referred to shed light on the causes of the larger movement. For example, the geographical range of the varying hare (*Lepus variabilis*) as a species is very wide, but that of the individual is extremely narrow. The species is found among the mountains of the North of Scotland. It has been met with in Cumberland. Sibbald notes it as an Orcadian form in his day. It occurs in the Swiss Alps, in Sweden, Norway, Lapland, Kamschatka, and about Hudson's Bay. Yet the individual never wanders more than a few miles from its breeding-place, and its change of habitat is regular. On the approach of winter it quits its summer residence on the mountain summits, and takes up a milder position, very often only farther down the same mountain-side. The chief advantage of this partial migration seems to be a readier supply of food, in a temperature sufficiently cold to provoke the fur to become white. With the return of summer it again betakes itself to the heights, urged thereto, no doubt, by breeding instincts, and the desire to escape the irritating accompaniments of the increase of insect life, in the less exposed parts of the hills. Thus one kind of partial migration: but there are others which cannot be thus explained—others in which neither breeding instincts nor food can have a place. For several seasons a little company of roe-deer (*Cervus capreolus*), varying from three to five, made their appearance, in August or September, in a protected plantation bordering on the banks of the Avon, Linlithgowshire. Cautious, wary, timid, they skulked about for two or three weeks, few persons in the district being aware of their presence. The

* "Narrative of an Expedition to the Polar Seas," 1820—23, translated by Col. Sabine (1840).

† "Fauna Boreali—Americana."

‡ "Expedition to the Yenissei."

visit was not a random one. It was for a good many years seasonally regular, and may still continue. As one object in view throughout this paper is to suggest to thoughtful readers how many points, even in commonest phenomena, wait for satisfactory explanation, I indicate again my own leanings in the following queries:—Was the presence of the roe in a district surrounded by a teeming population, and remote from its present breeding ground, to be traced to the working of an instinctive drawing towards localities once noted for the numbers of these forms? Had the direction of home been wrought hereditarily into its psychical nature, and were these visits the proof? How otherwise, for example, could the young cuckoo, which so often lingers a month or six weeks behind the parent birds, join them in a far-off land? I attach much weight to *long-continued* climatal conditions, and even to periodic changes of temperature in questions of this sort; but neither of these goes to the root of the matter. The explanation is more likely to be found in the facts of transmitted memory, a somewhat metaphysical phrase, but, nevertheless, one which is almost within reach of verification. No doubt, most mammals had once a far wider range than now—a fact which has most important bearings on migrations, and also on the relations of the great extinct animals of Quaternary time to our present fauna. Why should it be deemed so strange to find the remains of animals, held to be widely separated both as to the marks of species and geographical range, lying together in the same cave earth or the same gravel heap? The roe-deer is abundant in most countries of the Old World; but how different its associates, say, in Amoorland, where Dr. Von Schrenck found it, and in Scotland! So with birds.* The stork may leave its bones where black and white cattle feed in Dutch meadows, or by river banks in Central Africa haunted by antelopes and lions. Brehm found it in the Soudan — in September—still making for the south. Cuvier describes the tiger (*Felis tigris*) as confined to the warmest parts of Asia.† But Von Schrenck‡ records it as an ordinary resident in Amoorland.

Fig. 1.—The Lemming (*Myodes lemmus*).

* "Migrations of Birds:" "Science for All," Vol. I., p. 150.

† "Tableau Élémentaire," p. 118 (1798).

‡ "Reisen und Forschungen im Amur-lande in der Jahren 1854-6."

He has shown that it has crossed the ice in latitude 50° N., and penetrated into the island of Saghalin. With such facts before us as those stated above, it is hardly possible to resist the inference, that the migration of mammals is, in great part, to be accounted for by the impulse of an inherited desire towards the areas of their original natural distribution. If the reindeer and the lemming push their way from the north, the northern grey squirrel to the east, and the American bison, as if possessed by a wandering fury, occasionally force its way past towns, and villages, and farm steadings, to localities far from their present homes; no explanation answers all the cases so well as the theory of an inherited drawing to places which were the natural habitats of their ancestors. The presence of the tiger in latitude 50° N., and also at the tropics, is not to be traced to what we might call abnormal "push" on the part of some tigers, or to the noble beast's bare love of adventure, but simply to the fact that these parts were included in its original natural range. An instance from among birds will best illustrate this. Suppose all the information a British naturalist had of the elder duck (*Somateria mollissima*) was confined to those that visit the Isle of May, in the Firth of Forth, and the Flannen Isles, the most remote of the outer Hebrides, with the exception of St. Kilda; he would most likely be content to say: "This bird visits us yearly from the far north for the purpose of breeding." But we know that their favourite nesting ground is in the far north itself. Yet year by year a few pairs visit these islands, thus nesting on our coasts. Now, while positive

Fig. 2.—The Reindeer (*Cervus tarandus*).

knowledge is impossible here, is there any explanation more in the line of the facts, than the theory that the birds which visit us are the descendants of those which originally had their centre of distribution thus far south? And so as to mammals. It is most likely that the territorial limits of their present migrations were originally held throughout the year by the ancestors of the present migrating species.

Birds have once and again been referred to above, but no allusion has been made to the migration of fishes. Pennant's vivid description of the herring (*Clupea harengus*)* early attracted the attention of naturalists to its changes of locality. It reads like a tale, charming, but not true. The distribution of the species is very wide, but there is no proof that the individual wanders far from the place of its birth. What used to be regarded as migration on the part of this fish, is now known to be no more than a change from deep water to the neighbouring shores. But the herring of the American coast is identical with our own—a fact which tells against the temperature theory. Temperature may be a factor in determining migration, but it is not a leading one. In some cases even it can have no weight. For example, the fish fauna of the Mediterranean is, in very many instances, identical with that of Britain; and Mediterranean forms are met with in considerable numbers on the coast of Japan, and in the West Indies. Again, both American and South African species sometimes find their way to our shores. The writer has a fine specimen of the United States sturgeon (*Acipenser maculosus*) which was taken in the Firth of Tay. Two specimens of the spinous shark (*Echinorhynchus spinosus*) were some time since sent to him from the Firth of Forth, several years intervening between them.

The seasonal migrations of marine species are to be traced to conditions of food and breeding, and these furnish the best illustrations of migratory habits. Such changes, however, are to be distinguished from those sporadic movements under which forms, rightly accounted marine, are known to venture into fresh water and ascend river courses for hundreds of miles. Instances might be named among the families of salmon, sturgeons, herrings, and lampreys. These again are matched by fresh-water species, as the sticklebacks (*Gasterosteidæ*) and our common river-trouts, which are known to make excursions into the sea. But passing away from these, the common salmon may be taken as a good illustrative example of fish migration. Its habits in this respect are so well known, that we may dismiss them with this reference. The only point I wish to notice is the influence of man in restricting the limits of migration—a most important factor in the case of mammals, though not discussed above. It has been shown that, in some Scottish counties, salmon have forsaken rivers which formerly they frequented.† The pollution of the waters by coal and iron pits, chemical works, &c., has rendered them no longer safe for these fish, and their presence in some of the streams would be regarded with wonder by the people. Yet they occasionally brave all dangers, and push their way back to ancestral breeding-places. The habit of the roe-deer has been referred to as an illustration of this among mammals, and it is interesting to meet with the same among fishes. Many examples might be given. Some years ago several salmon were found dead or dying in a ditch in East Lothian, into which the drainage of fields enriched by artificial manure was poured. This ditch had originally been a feeder of a small stream which found its way to the Firth of Forth, some miles distant. But the "oldest inhabitant" had never seen salmon in the place before. In Linlithgowshire some appeared in a streamlet which, after uniting with others as a good-sized "burn" joins the Avon, a tributary of the Forth. For fifteen or sixteen years this streamlet was too foul for even minnows to live in.

I state these facts with a view of calling attention again to the influence of inherited love for, and drawing towards, ancestral localities. This, indeed, is the main inference insisted on in this paper. It points to a force which explains much in the migration of mammals otherwise most obscure, a force, moreover, which is equally powerful in the lowest class of vertebrates and in the highest.

* "Arctic Zoology" (1784).

† "Scotsman," April 7, 1881.

SPEAKING MACHINES.

By William Ackroyd, F.I.C., etc.

About fifty years ago, Sir David Brewster, speaking of the various kinds of talking engines that had been devised, and of the experience that had been gained in constructing and working with them, said, "We have no doubt that before another century is completed, a talking and a singing machine will be numbered among the conquests of science." The conquest has now been made, and in so wonderfully complete a manner that not only may we have a machine singing and speaking with the operator close to us, but we may likewise have singing and speaking with the performer twenty or more miles away! A little machine resting on the table, apparently consisting of a revolving drum, which may be steadily and uniformly turned by a handle, will call out to all clustering around it, "How do you do?" "Good night," &c., and anything else the operator may have predetermined; or a lesser contrivance still will reproduce any sounds that are uttered before a transmitter a good many miles off; and so well, that the notes of a cornet, the song of a vocalist, and the words of a talker are distinctly heard all over the room. These are, indeed, conquests of such interest that one longs to hear about the various battles of mind against matter by means of which they have been made.

No one knows when man first began to speculate as to the possibility of making machines that would talk. It must have been in times when, for the purposes of fable, sticks and stones were supposed to speak; when ideas regarding sound and voice were so crude that one imagined the possibility of burying the voice, as in the legend of Midas's barber; and when philosophers were so much in the dark concerning these things that any step they might have taken would have been, without doubt, a wrong one.

From those ages of uncertainty we pass to the middle of last century. Men of science had now obtained correct ideas as to the nature of sound, and were beginning to learn the conditions necessary for the production of articulate sounds. It was seen that while the vocal cords were designed to produce voice, the various parts of the mouth were used to modify it. They accordingly took a hint from the human mechanism in their first attempts at making speaking machines.

It is not our intention here to trouble the reader with another account of the organs by means of which we speak—the cartilages, ligaments, and muscles with hard names that originate and modify the sound of the human voice (p. 43). But, in passing, we may remark that an ordinary bobbin, with a couple of stretched india-rubber bands over one end, is a rough representation of one portion of the human apparatus. The tube within the bobbin represents the wind-pipe, and the stretched india-rubber bands over the end of it stand for the vocal cords; and just as a lad, by blowing down such a bobbin, produces a musical sound, so a human individual, by sending a supply of air up his wind-pipe from the lungs, and bringing his vocal cords to the requisite tension and nearness, originates a musical sound. This sound is now modified by the throat, tongue, and lips, to produce speech. Hence, if one were to mount over the india-rubber bands of our bobbin a cavity with artificial lips and tongue, we should have produced a very simple kind of speaking machine, by means of which two or three words might be distinctly articulated. Procure an orange, and make a round hole in the rind large enough for one end of the bobbin to be inserted (Fig. 1). Make a slit opposite the circular hole, and carefully remove the inside of the orange. On blowing down the bobbin now, and closing the artificial lips twice quickly, *Ma-Ma* will be clearly rendered.

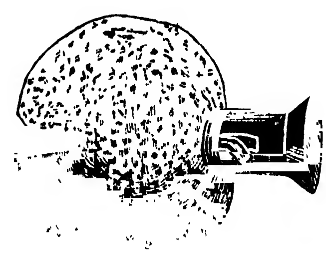


Fig. 1.—A simple Speaking Machine.

Upon an analysis of the sounds that are used in speech, it is found that the vast variety of words which make up a language are formed from the combination of a few elementary sounds; just as the untold number of chemical compounds in nature are formed from the union of a comparatively few elements. If there were a proper correspondence between our written and our spoken language, each of these elementary sounds would be represented only by one character. There is, however, a want of correspondence between the characters of our written language

and the sounds of our spoken language, which, as Sir Charles Wheatstone has remarked, has been a great obstacle to the proper understanding of the real elements of speech. To quote the same authority: "A child is taught that the letters W, H, Y make the syllable 'why'; now, if we examine the sound of this word, we shall find it to be formed by the rapid succession of the vowel sounds U, *ah*, E. In attempting, therefore, to imitate by artificial means the sound of this word, we should pay no regard to the letters of which it is formed; the elementary sounds alone are the objects of our attention. The same observation is generally applicable to the words of our language." Hence, to make a speaking machine, it had first to be ascertained how to produce each of the elementary sounds; then, by a number of keys like those of a piano, they purposed combining these elementary sounds to form words, as notes in music are combined to form chords.

With a wise perception, the Imperial Academy of St. Petersburg accordingly offered a prize in 1779 for an investigation touching the nature of the vowel sounds—*i.e.*, the five elementary sounds expressed by the letters *a*, *e*, *i*, *o*, *u*, which are formed out of the sound produced by a continuous expiration, the mouth being kept open, but having the form of its aperture changed for each vowel. The questions the Academy proposed were these:—

1. What is the nature and character of the sounds of the vowels A, E, I, O, U, so different from each other?

2. Can an instrument be constructed, like the *vox humana* pipes of the organ, which shall accurately express the sounds of the vowels?

The prize was won by Professor Kratzenstein, who, after examining the positions of the various organs, and measuring the apertures of the lips, teeth, and other parts, constructed a series of tubes, shown in section in Fig. 2, which distinctly

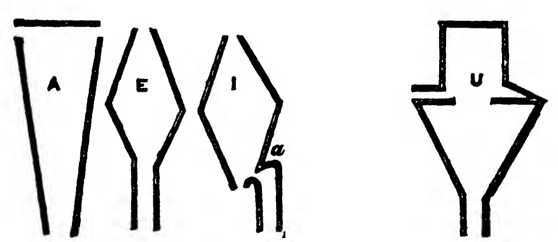


Fig. 2.—Kratzenstein's Vowel Tubes.

pronounced the vowels A, E, O, U when their lower ends were blown into through a reed. To produce I, it was merely necessary to blow into the pipe, *a b*, of the I tube. Just half a century after, however, Professor Willis, of Cambridge, in repeating Kempelen's experiments, presently to be described, arrived finally at the conclusion that the forms of Kratzenstein's vowel tubes were quite arbitrary, as he obtained all the vowel sounds from tubes of exactly the same form by simply altering their dimensions. To commence with, Willis found that by employing a shallower cavity than Kempelen had used, he could obtain the vowels without inserting his hand. Let A B (Fig. 3) represent the shallow cavity, and R a reed in the pipe connected with it. He discovered that by sliding a flat board, C D, over the mouth of the cavity while the reed was sounding, the whole series of vowels were uttered in the order U, O, A, E, I. And now, instead of using a shallow cavity, he employed a telescopic or compound tube, having the reed in the plug at one end. By sliding the telescopic tube out while the reed was sounding, he obtained the whole series of vowels in a determinate order—I, E, A, O, U, or U, O, A, E, I, according to the length of it pulled out.

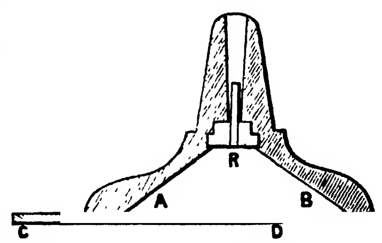


Fig. 3.—Kempelen's Apparatus, as modified by Professor Willis.

It often happens that nearly the same discovery or invention is made by persons living widely apart, and without any knowledge of each other's proceedings; and it appears, in the case under consideration, that while Kratzenstein was thinking and working over the problems proposed by the Imperial Academy of St. Petersburg, there were Von Kempelen, of Vienna, engaged in a more extensive investigation of the subject, and in France the Abbé Mical making large speaking heads.

It is difficult to give an idea of the apparatus Kempelen constructed without diagrams. His first attempt may be described as a nearer approximation to a copy of the human speech organs than any that had hitherto been made. There was in it only one cavity, A B (Fig. 3), whose shape and dimensions had to be altered according to the nature of the letter which had to be uttered, and this was managed by placing his hands in various positions within it. The sound to be modified was produced from a reed, R, placed within a pipe which was in communication with the cavity. Only poor

results were obtained with this first venture, and in a subsequent attempt he employed a hollow oval box, so divided into portions, and attached by a hinge, as to resemble jaws. With this he produced the sounds A, O, OU, and an imperfect E, but no indications of an I. He still, however, persevered, and in a couple of years had completed a speaking machine which would pronounce the consonants P, M, L, and by means of these and the vowels it would pronounce he obtained from it the words mamma, papa, aula, lama, &c. He went on further improving his machine, and it appears that finally he was able to make it utter words and sentences like the following:—*opera*, *astronomy*, *Constantinopolis*, *Leopoldus secundus*, *vous êtes mon ami*, *je vous aime de tout mon cœur*, *venez avec moi à Paris*, *Romanorum imperator semper Augustus*, &c.

Mical is said to have never published any details of the speaking heads which he exhibited before the French Academy in July, 1783. From the accounts of contemporaries who saw them they would appear to have been masterpieces of ingenuity. The heads covered a hollow box, the different parts of which were connected together by hinges. In the interior were artificial glottises of different forms over stretched membranes and, according to Vicq D'Azyr, the air passing through these glottises was directed on to the membranes, and from the combination of the sounds produced there was thus obtained a somewhat imperfect imitation of the human voice. A key-board was attached to one of the heads, which a person properly initiated could finger in order to make the head speak. So far as the poor abbé was concerned, the heads appear to have been a source of anything but satisfaction, as he is said to have smashed them up on being disappointed of the reward which, on the recommendation of the Academy, he had expected from the Government, and shortly after his disappointment he died.

Perhaps the most recent attempt at making a speaking machine of this order is that of Faber, of Vienna. As big as a parlour organ, it has a vibrating reed of variable pitch for its vocal cords; an oral cavity, whose form and dimensions can be quickly changed by fingering the keys on a key-board; a rubber tongue and lips, to form the consonants, and when performing it is said to utter something like articulation in a monotonous organ note.

The tremendous amount of labour entailed in making these machines, together with the poor results obtained from them, acted as a deterrent in the prosecution of this branch of discovery and invention. The dream of the inventor was to make a machine with voice so powerful that it might be employed to command armies, and of articulation so perfect that it would serve for all time to perpetuate the pronunciation of nations. In both he was disappointed. There seemed to be no discoverable way of originating speech so powerful, so perfect, or so easily performed as that ready to hand in our vocal organs. And it will be remarked, as we proceed, that the epoch-making inventions and discoveries of the last few years have been made in new fields, and in the endeavour not to *originate* articulate sounds, but to *reproduce* them. Before we proceed to describe these machines for reproducing speech, it will be necessary for us to give some account of certain facts which were known before the inventions were made, and which serve as a proper introduction to their explanation.

When the prongs of a tuning-fork are struck, a sound is emitted and the limbs tremble or vibrate intensely. The motion of the prongs is a minute and rapid to-and-fro motion, during which the limbs may be said to approach and recede from each other with extreme rapidity. If, therefore, a small piece of metal, as, *e.g.*, the point of a pin or needle, be attached to one side of a tuning-fork by means of wax (Fig. 4), then this point of metal will make rapid excursions to and fro when the fork is made to sound. It is apparent, therefore, that if the point be hastily drawn along the surface of smoked glass while the fork is sounding, there will be a wavy trace left (Fig. 4, *b*). The phonautograph of M. Leon Scott is an instrument based on this principle. A fixed and stretched circular membrane, with a light point of metal attached, being made to vibrate, like the ferrotype plate of a telephone, by speaking into it, a smoked cylinder revolves before it at a uniform speed, so that the point traces out the curve peculiar to the sound which has been uttered.* Perhaps the most delicate arrangement of this kind ever used was the preparation of a human ear made by Dr. Clarence J. Blake, of Boston, for Professor Bell.

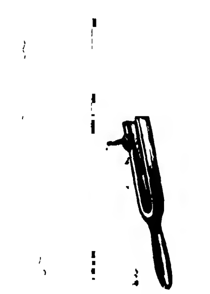


Fig. 4.—Wavy Trace of a vibrating Tuning-fork.

* "Science for All," Vol. I., p. 131.

This was simply the ear taken from an anatomical subject, suitably mounted, and having attached to its drum a straw which made traces on a blackened rotating cylinder. The difference between the traces of the sounds spoken into the ear was very clearly shown. In these various attempts to record sound it was requisite to have the point or marker moving at a true parallel to the blackened surface, and the nature of the curves was all one had to determine the nature of the sounds which had been uttered. In 1877, Thos. Alva Edison, the well-known American inventor, devised the *phonograph*, a speech-reproducing machine of marvellous simplicity, which, in general terms, may be described diaphragm is set vibrating, the metal point, in its excursions to and fro, indents any soft substance that may be in front of it. It is, moreover, found that if such a soft substance be drawn before the kicking pin, the nature of the depressions produced, or, in other words, the nature of the minute ridges and valleys carved out, depends entirely upon the character of the sound which sets the diaphragm with its dependent pin vibrating; and if the converse operation could now be performed—*i.e.*, if the indentations could now be drawn in front of the pin point in the exact order and at the same speed with which they were originally produced—then the diaphragm would be

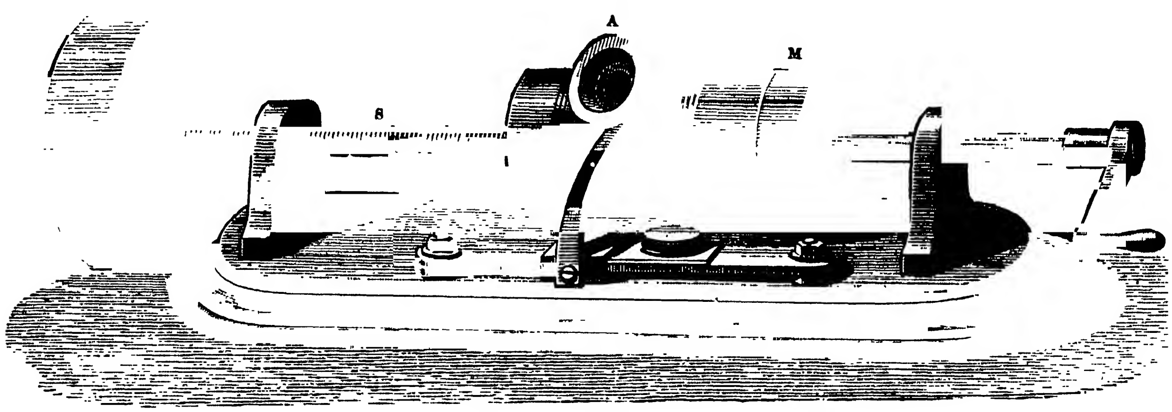


Fig. 5.—The Phonograph.

as a phonautograph with its point moving in a plane at right angles to the surface of the cylinder, and thus giving kicks instead of traces when the membrane is vibrating. We shall now proceed to describe this machine more minutely.

The essential parts of the phonograph are the mouthpiece, A, and the drum M (Fig. 5). At the back of the mouthpiece there is a diaphragm of thin sheet metal, which is set vibrating when one speaks into it. This vibratory motion is communicated to a metal point, or marker, which, in the earlier forms of phonograph, was directly attached to the back and centre of the diaphragm. It is found better, however, to have the point, *p* (Fig. 6) attached to a piece of steel-spring, *s*, with an india-rubber cushion intervening between the spring and the diaphragm, *d*. It will be readily understood that when one speaks into the phonograph, and the

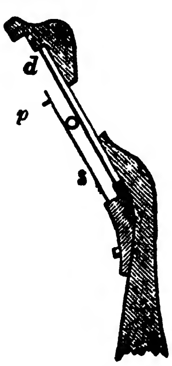


Fig. 6.—How the Marker of the Phonograph Works.

made to vibrate exactly as before, and, communicating its vibrations to the air, would reproduce the sounds originally spoken in front of the mouthpiece. It will therefore be seen that the philosophy of the whole process consists simply in taking a permanent impression of a very complex compound vibration, and using it again as a mould to reproduce that vibration. For this to be done efficiently, there is a drum, M, with a spiral groove in it, and this is revolved in front of the vibrating pin. The pin dips into the groove. The axle of the drum at S is likewise spirally grooved and fitted to a knife-edge, so that as the drum is revolving it moves along at such a rate that the pin never leaves the drum groove. To insure uniformity of speed, various means are resorted to, but most commonly clock-work is employed. In some American phonographs, however, the uniformity of speed is obtained by having a heavy fly-wheel connected with the handle, as in Fig. 5. A sheet of tin-foil being fastened round the drum, one makes it revolve, and at the same time speaks into the mouthpiece. The tin-foil is impressed with the

peculiar indentations that are produced by the speech uttered before it. And now, when the drum is slid back, so that the pin may rest at the commencement of the depressions, the drum has only to be set revolving at the same rate as before for the sounds to be reproduced.

The speech-laden tin-foil appears as if indented with parallel rows of dots and dashes. Some idea of the appearance is given in Fig. 7. These indentations may have the power to reproduce a speech or a song, the loud crow of the farm-yard, or the loud whistle of a country bumpkin. Nay, they may even reproduce the harmonious efforts of two or three vocalists.

Fig. 7.—Speech-laden Tin-foil.

The instrument, moreover, is not without its peculiarities of utterance. It has a pious horror of serpent-like hissing sounds, which it can only with extreme difficulty be made to repeat, so that instead of the words, "steady, boys, steady!" of our well-known patriotic song, we get from it, "thteady, boyth, thteady!" The real elements of speech, however, which have been uttered before it are reproduced faithfully whichever way the drum is revolved. Thus if *baaoot* or *baaeet* be pronounced in front of the phonograph while the drum is revolving at a uniform rate, the sounds *tooaab* or *teeaab* will come out if the motion be reversed; in other words, the elements of speech here, whether vowel or consonant, appear to have this peculiarity—that a motion of the drum either way will reproduce them. On this account it has been suggested that we only regard that as an elementary speech sound which is uttered by either direct or reverse motion of the tin-foil which has been impressed with it in the phonograph.

It is not at all remarkable that the performances of such an instrument as this should have been regarded at first with a feeling of incredulity; for it really appeared astoundingly wonderful that a revolving drum encased in tin-foil should utter passages from standard works, &c.; and in one eccentric member of the French Academy this incredulity was so strong that he declared to the laughing assembly that the sounds heard were the effects of ventriloquism. His astonishment must have been much greater still, however, when M. du Moncel gave a demonstration with a "singing condenser." Withdrawing to a room, in company with M. Faye, he closed the door and sang. His voice was heard in another room coming from a number of sheets of tin-foil interleaved with prepared paper, and connected with an induction coil. This singing condenser, due to our countryman, Mr. Cromwell F. Varley, has since become a "speaking condenser," and we shall therefore have to describe this, the latest of speaking machines. And here we would add that the wonderful fertility of modern science must have struck even those who are perfectly familiar with its methods and results, and with ten-fold more force must it have impressed general readers. When Bell had perfected his telephone, it appeared to leave little, if anything, to desire. Perfect in articulation, capable of being used over comparatively long distances, it seemed an instrument unique in every respect, and of such a nature that none other could be devised either to aid or supplant it. Yet four short years scarcely passed ere it was supplanted as a transmitter by the microphone,* and its capabilities as a receiver have been approached, if not equalled, by the speaking condenser, and Preece's telephone—instruments we have next to speak about. First, then, as to the condenser.

A condenser is a series of alternating sheets of tin-foil and some insulating substance like shellacked paper. These are generally placed in the oblong box upon which an induction coil rests. If there be, say, nine sheets of tin-foil, counting from the top (Fig. 8), all those represented by odd numbers are connected at one side, and all the even-numbered sheets are joined up at the other. Wires leading from these two sets of metal sheets are joined up to the metal supports of what is known as the contact breaker, a device employed for making the primary current intermittent. Varley, as we have before hinted, discovered some years ago that if such a condenser be connected to the secondary wire of an induction coil, while the primary includes a Reiss transmitter like that figured in Vol. I., p. 182, then upon singing into the transmitter the notes are reproduced by the condenser. Our idea of the arrangement will be materially aided by a diagram. In Fig. 8, C represents the alternating sheets of tin-foil and an insulating substance. The sheets of metal are joined up to the secondary wire of the coil, which is here represented as one of a pair of parallel wires (II). The primary circuit (I) includes the battery, B, and the transmitter, T. Upon singing into T, C gives out similar notes. By a slight

* "Science for All," Vol. V., p. 170.

alteration of conditions, it has been made to reproduce speech too. M. Dunand found that when a carbon microphone took the place of the Reiss transmitter, as represented in the diagram, and a battery was included in the secondary circuit along with the condenser, then speech could be reproduced—*i.e.*, if one talked to the carbon microphone the condenser reproduced the speech. These results were communicated to the French Academy by

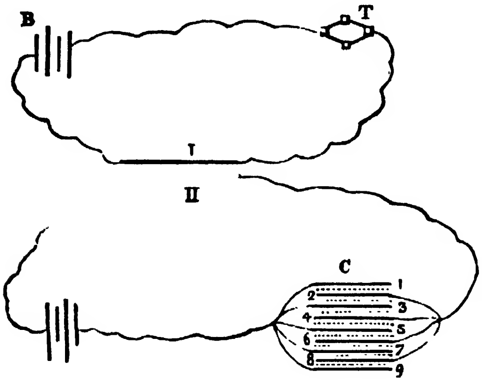


Fig. 8.—A Speaking Condenser.

M. du Moncel, who was apparently in an awkward position; for when he received M. Dunand's communication he had already seen the condenser used successfully instead of the telephone by M. Hertz, who requested him to be silent on the matter. Here, therefore, as in a great many other cases of invention and discovery, two independent workers, quite unknown to each other, were simultaneously successful.

We have now to turn to Preece's telephone, invented in 1880, an instrument of even greater simplicity than the one devised by Bell. The resistance which is offered by a wire to a current

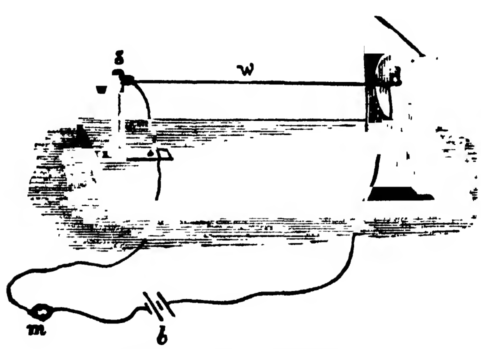


Fig. 9. - Preece's Telephone.

of electricity raises its temperature; so that if there be a rapid variation of the current, there will be a rapid variation of the temperature, an alternation of heatings and coolings. Heat expands or lengthens, cold contracts or shortens a wire. It is upon these principles, in addition to a few others already enunciated, that Preece's telephone is based. A general view of it is shown in Fig. 9. There is a disc, *d*, of the same nature as the ferrotype diaphragm of the phonograph, so that when made to vibrate in a particular manner it will emit sound. On a stout base of mahogany a brass support, *s*, is so attached that it can slide and be fixed at any distance from *d*. A wire of about six inches in length is connected with *d* at one end, and with the tip of a screw in the support, *s*, at the other. To the ends of this stretched wire, *w*, two other wires are connected, so that a complete ring (circuit) may be completed, including the earth, a microphone, *m*, and a battery, *b*. Now, when a current of electricity passes through a thin wire like *w*, the heat developed makes the wire lengthen, and as it exposes a large amount of surface to the surrounding space, it as readily cools and shortens. We have already learnt that a microphone produces a most rapid variation in the current which passes through it,* and therefore, in this case, a person speaking into the microphone at *m* rapidly varies the strength of the current passing through the wire, *w*, from the battery, *b*; or, looking at the phenomenon from its thermal aspect, we have a rapid alternation of heatings and coolings, or of lengthenings and shortenings of the wire, *w*, whereby such a state of vibration is communicated to the disc, *d*, as will make it give out similar sounds to those which have been spoken in the neighbourhood of *m*.

Preece found in his experiments that wires 0·001 inch in diameter gave the best effects; and so far as materials are concerned, *very clear* sounds were obtained with platinum, *clear* sounds with palladium and iron, *faint* sounds with copper and silver, *very poor* results with gold, and *very variable* ones with aluminium. One curious result was that hissing sounds could not be reproduced by this means.

From what we have said, it will be seen that the problem which exercised the minds of a few pioneers in the last century was one of no mean order, and complete success was reserved for their followers of to-day. How complete that success has been is evident when a man in his senses declares that the performance of a speaking machine is due to ventriloquism, so well is the human voice simulated; and, indeed, the wonderment its performance excites in the minds of the

* "Science for All," Vol. V., p. 170.

ignorant cannot be adequately expressed in words. It is of the same nature as that exhibited by the savage chief who, when sent from the missionary Williams to his wife with a message written on a chip, was so surprised at what seemed to him the silent speech of the bit of wood that thenceforward he wore it suspended from his neck. But we cannot imagine what the effect would have been on his savage mind if, instead of a chip, he had had given to him a roll of speech-laden tin-foil, which, upon being put upon the drum of a phonograph, had uttered the message in his presence!

ANTS, AND THEIR WAYS OF LIFE.

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As may be learnt from the writings of more than one ancient author, it is several thousand years since ants first commanded attention by reason of their curious habits; but it is only in modern times that any attempt has been made to thoroughly and systematically investigate these, and to ascertain what amount of truth there is in the belief that ants are endowed with a large amount of intelligence and of reasoning powers.

Before, however, discussing the views of recent observers on this interesting point, it will be necessary to learn something of the ordinary routine of an ant's life; to see how the nest, or, as it is technically called, the *formicarium*, is constructed, and what uses it subserves; and to find out (so far as we may) the domestic economy and relations, *inter se*, of the inhabitants.

Fig. 1.—Section of an Ants' Nest.

As incidentally mentioned in a previous paper, various kinds of ants make various kinds of nests. Some merely excavate burrows in the earth below a stone; others live below the bark of dead trees, and make more or less extensive galleries in the decaying wood, in some cases working up the tissues of the trees into a paper-like substance, with which to construct part of the nest; a third class raise mounds or hillocks on the surface of the earth, and live in the interior of the hill, or in excavations below it; while yet another construct hanging-nests in trees by glueing the leaves together; and a few others inhabit parts of living plants which they have adapted for their use. Other forms of nests might be mentioned, but, from the examples given, it can readily be imagined that just as the modes employed in constructing the formicarium are very varied, so are the habits of the ants themselves. It will be well, therefore, to select one particular species as the subject of our first investigations, and, having ascertained what its manner of life is, then proceed to see in what respects those of some other ants differ.

The ant, which by its wide distribution, comparatively large size, and the conspicuous nest that it constructs, seems to present itself as an appropriate subject to select for observation, is the large wood or horse species, *Formica rufa* (Fig. 1, p. 109). This is the ant which constructs the large mounds of dead vegetable *dĕbris*, so familiar to most of us as "ant-hills" (Figs 1, 2, and Fig. 2, p. 112). These hills sometimes attain a height of three or four feet, and contain many thousand inhabitants; but for our purpose it will be well to select a smaller and more recently-founded colony. This, we can see, is a dome-shaped accumulation of dead pieces of plants, with sometimes a few stones, particles of earth, &c., intermingled. The vegetable components of the nest vary according to the situation. In a fir-wood they will be found to consist almost entirely of the dead fir-leaves or needles, but in other woods they may be the stalks of dead leaves, bits of dead grass, and so forth. Whatever material is most suitable, and, at the same time, most easily got, is used by the ants.

Whatever the material may be, it is so arranged that the dome of the nest is, to a certain extent, waterproof, and, at the same time, a number of doorways are left to permit of the entrance and exit of the inhabitants. These doorways communicate with winding passages and galleries in the interior of the nest, and from these again, in older nests, passages descend into the earth, where another series of chambers and galleries exist, in which the inhabitants live in winter. In recently-made nests there are no underground works. These are made afterwards, and, as well as the dome, are increased in size as the population of the formicarium increases. As the nest gets old the outer lower portion of the raised structure decays, and becomes more solid, and is not used by the inhabitants, but abandoned to various other insects, who find in the decaying mass food and shelter. From the ant-hill, especially if it be an old one, various well-marked paths—an inch or more wide—may be seen going in various directions, and reaching to the distance of sometimes several hundred yards. Along these roads crowds of ants may be seen hurrying to and from the nest—those that are going to it often laden with some piece of material with which to add to the structure of the hill, or perhaps with their "sucking stomachs" filled with food for the larvæ. The roads lead to the favourite hunting-grounds of the inhabitants of the nest, or to one or more new colonies; and, from the greater traffic on them near the ant-hill, are there broader and more strongly marked, as all the vegetation has died, and left the well-trodden bare earth. From the number of passengers going backward and forward upon such a road, attempts have been made to calculate the number of inhabitants of a nest of *Formica rufa*, and M. Forel arrives at the conclusion that there may be as many as 500,000 workers in one nest, though in many cases the number may be 5,000, or less, according to the age of the nest.

The inhabitants of the formicarium consist of workers, and fertilised and wingless females, and, for a very short time, of males and winged females. When the winged individuals (male and female) leave the pupa state they remain in the nest for a few days, attended by the workers, but on some fine morning they come out, climb about the dome, or on some neighbouring plant, and pair there, some, however, going off to a greater distance. At this time the workers are in a great state of excitement, and run hither and thither, looking for the fertilised females, which are then carried into the nest. The males fly away, and, being unable to feed themselves, die in a few days, or are slain by birds or spiders, or by other ants. Many females, too, are doubtless lost when they have wandered too far from the natal formicarium. After a female has been fertilised she takes steps to get rid of her wings, which are now of no further use. This she accomplishes by moving them backwards and forwards, and shaking them violently till they drop off. In getting rid of their wings they are often assisted by the workers. Thereafter the rest of the life of the female is spent in laying eggs from time to time, and she takes little or no part in the work of the nest. Upon the workers devolve all the labours of the community. By them is the nest constructed, kept in repair, and added to; the young, be they eggs, larvæ, or pupæ, fed or nursed; the females, and others, who have not been able to go out in search of food, fed from the supply in their sucking stomachs; and finally, the nest defended if attacked by some enemy. In a word, the sole end and aim of every ant seems to be the common good, and not the welfare of the individual. In fighting they do not employ much strategy, but rush fearlessly and furiously on against the enemy, biting with their powerful mandibles, or discharging —for they are not provided with stings—from the ends of their abdomens, the contents of their poison reservoirs.

The duration of life of an ant after it has reached the adult stage is very uncertain. The males, as we have seen, live for a few days only, but the females and workers have a longer span of life, extending even to four, five, or perhaps even a greater number of years. How long a formicarium may flourish varies. After a while females cease to be produced in it, and the city gradually perishes from want of inhabitants, but other causes may determine the extinction—such as the failure of the food supply, the too-near neighbourhood of a flourishing rival city, &c.

In addition to its proper inhabitants, the nest of *Formica rufa* (as of several other ants) contains other inmates. Some of these, as have been mentioned, live in the older and deserted parts of the nest, but there are others which live in the inhabited portions, and are either able to protect themselves from the owners of the nest, or else live on good terms with them. In the latter case the exact relations between the host and the guest are not very clear, though in some cases it would appear that the ants obtain from their guests some sweet secretion, and in return give them protection. These guests—invited or uninvited—consist chiefly

of insects—with one or two allied animals (such as mites and woodlice)—and include beetles, two-winged flies, and at least one moth. Like other ants, *Formica rufa* cultivates, as it were, certain species of plant-lice (Fig. 3), and their roads frequently lead to trees much frequented by the latter, which live in peace under the protection of the ants. The latter, in giving this protection, are far from disinterested, for the aphides are their cows, and are regularly milked by the ants. If we examine a plant-louse or aphis we will see that it is furnished near the end of its abdomen, with two little conical projections. From these it can discharge a small quantity of a sweet fluid, much

. 2.—Section of an Ant-hill.

relished by the ants. When an ant wishes to milk an aphis, it gently strokes the latter with its antennæ, upon which the aphis discharges a drop of the fluid, and the ant laps it up. This is an operation that any one may easily observe for himself.

Unlike the honey bees, the females in an ants' nest are not limited to one.

On the whole, *Formica rufa* is not one of the most intelligent of ants, but as it has served our purpose in letting us see what a formicarium is like, we will now pass on to another ant, whose habits are very curious. This is the Amazon ant, *Polyergus rufescens*, a species not uncommon in some parts of Europe. Its nest is constructed in the ground, and covered with a dome of earth. The Amazon ant is not provided with a sting, nor does it throw its poison out forcibly, like *Formica rufa*, but it is an insect of amazing courage, and gifted with a high degree of intelligence. The most remarkable fact in its history is that being unable to construct its own nest, to nurse its young, or even to feed itself, it makes slaves of other ants, and compels them to perform these offices for it. The ants it enslaves belong to the species *Formica fusca*, sometimes called from its colour the jet or negro ant, and the manner in which the slaves are obtained is as follows. Having ascertained (perhaps by means of scouts) where a nest of the negro ants is situated, an army of the Amazons (varying in number according to circumstances, but usually between 300 and 1,200) marches in a body to the nest that is to be attacked. The army consists of workers only, and they have no commander, though there is usually an advance guard, which, after leading for a little, retires to the rear of the army, other workers taking its place. On arriving at the nest they rush furiously at its guardians, overpower them, even if the weight of numbers is on the side of the assailed, and, entering into the nest, seize upon the pupæ or cocoons, and return to their own nest, where the spoil is handed over to the slaves, and by them the captured pupæ are carefully tended till they arrive at the adult stage, when they, too, become slaves. In this way the supply of slaves is kept up and increased. In their expeditions, the Amazons march with great celerity, and accomplish their work so quickly, that in less than an hour an army may have set off, stormed a nest, and returned with the spoil. The masters and their slaves live on very good terms with each other, though all the work, except fighting, falls to the lot of the latter. Among so many remarkable facts as the history of this ant presents, not the least remarkable is the inability of the Amazons to feed themselves. That this is not fancy has been proved over and over again, and is beyond doubt, and additional proof may be gathered from the construction of the parts of the mouth. When an Amazon is hungry it seeks out one of the slaves, and pats it with its

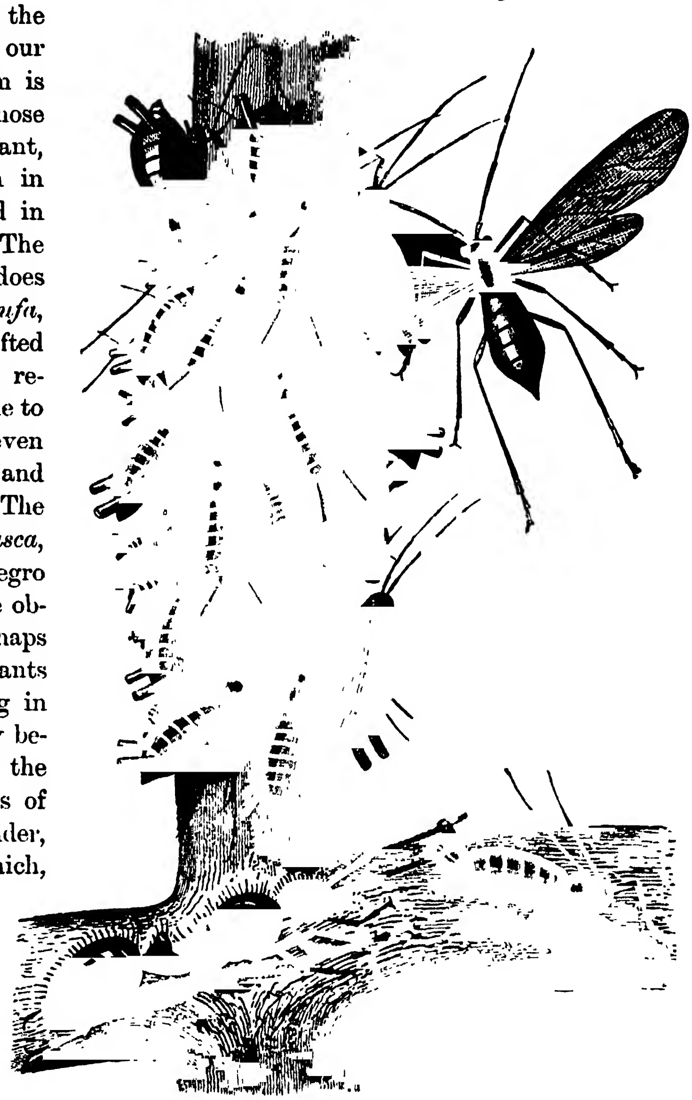


Fig. 3.—Ant milking Aphides or Plant-lice.

antennæ, whereupon the slave disgorges some of the liquid from the sucking stomach, and feeds its master. As a rule, it is only the cocoons of the workers that are carried off by the Amazons when they attack a nest; the pupæ of the males or females would be of no use to them, and being larger than those of the workers they know which to select. According to Huber, one of the earliest and most enthusiastic observers of the habits of ants, the slaves of the Amazons prevent their masters going

out on a slave-capturing expedition at the time when male and female pupæ predominate, but, though it is the case that the slaves do stop expeditions on certain occasions, it is very doubtful whether Huber's explanation is correct. In addition to *Formica fusca*, *Formica rufibarbis* is also enslaved by the Amazons.

The Amazon ant is not the only one that makes slaves, though it is one of the most interesting. *Formica sanguinea* is another species that employs servants, though, unlike the Amazon ant, it is not entirely dependent on its slaves. The species it enslaves, and which it captures in the same manner as the Amazons do, are several, and it sometimes happens that, not content with making a spoil of the pupæ, the nest itself is sometimes taken possession of, and the old nest deserted in favour of the captured one. There are several other species which have similar habits, but space will not permit of these being described.

In the sketch of the history of the horse ants, mention was made of the fact that they kept herds of plant-lice which they used as cows. Many other ants have the same habit of farming insects, which can supply them with a sweet secretion, but some of them take more entire possession of the aphides or other insects, keeping them in or near the nest, and so shutting them up, that no other ants can get to them. Amongst the ants which have this habit, is a common yellow ant, the *Lasius flavus*, which is a great miner, and being of a timid nature seldom ventures above ground. Its nest consists of galleries excavated in the earth below a stone or in a small hillock, and its food frequently consists in a great measure of the sweet liquid exuded by the aphides. The aphides that this ant keeps as milch cows are kinds which obtain their nourishment by sucking the juices of the roots of plants, so that the ant has no difficulty in keeping them in its subterranean galleries and in making these in places where the aphides can obtain food. This ant not only tends the aphides themselves, but is careful to preserve their eggs during the winter, and by placing them in the warmest part of the nest in spring hasten their hatching, with a view, of course, to obtain an early supply of food for themselves.

The statement by some old writers that ants stored up grain in their nests was long thought to be an error of observation, and it was supposed that the larvæ or pupæ being carried in and out of the nests by the workers had been mistaken for grains of wheat or other corn, to which they bear some resemblance. Recent observations, however, have shown that the old writers were correct, and that some ants do actually collect and store up seeds of plants which, or at least part of them, are in some manner used as food. Most of these ants belong to warm countries, and several species which inhabit the shores of the Mediterranean have this habit as I have myself seen. As much as one pound weight of seeds has been found in a nest. The nests, which are subterranean, are made in situations where plenty of seeds can be obtained, and among other places that have been observed to be selected (according to the late Mr. Moggridge) were the neighbourhood of a corn-dealer's shop, and of a bird-cage, which shows that the ants are not particular as to where they obtain the seeds. Nor are they at all scrupulous about robbing each other, and fierce fights often take place on this account. Though it is not difficult to believe that ants may be clever enough to collect and store up grain, yet that they should proceed further, and sow and cultivate them, having first prepared the ground for their reception, seems almost incredible. Yet that such is the case has been recorded in good faith, and though better evidence is desirable, and doubts have been expressed as to whether the crop is *intentionally* sown, as the history of the ant in question is most interesting we may profitably devote a little space to a discussion of its peculiar habits.

The agricultural ant, as it has been termed, is an inhabitant of North America. Its nest is constructed in the ground, and is sometimes covered with a slight mound. For a certain space round the nest the ground is carefully cleared of all vegetation and made tolerably smooth, as are the numerous paths which lead from it. The ants are very industrious seed collectors and may be seen toiling along their paths laden with seeds, which are stored up in granaries in the nest. In the cleared space round the nest there is frequently a patch or patches of a peculiar kind of grass which produces seeds that are much sought after by the ants. It has been stated that the ants make the clearing, and sow the seed of this grass on purpose to reap the crop, but evidence is yet wanting to show that the grass is intelligently sown and not accidentally. The fact remains, however, that on or round many nests there are crops of the grass, and that it is not destroyed like other vegetation by the ants.

The agricultural ant is not the only one that is credited with intelligently cultivating plants. The

leaf-cutting ants—also inhabitants of the American continent—are too well known in some places for the great havoc they cause by destroying the leaves of certain trees and other plants. So destructive are they that in some parts of tropical America it is almost impossible to grow some kinds of plants which are favourites of the ants. The nest is made in the ground, and is often of very large size. Mr. McCook, who has studied the habits of one kind of leaf-cutting ant that inhabits Texas, found in one case, that the hole left after the nest had been dug out by a man employed to destroy it, was twelve feet in diameter and fifteen feet deep. This space the ants had occupied with numerous chambers and connecting galleries—the largest chamber (about the size of a flour barrel) being at the bottom. From the nests numerous roads lead to places where an abundant supply of the proper kind of leaves can be obtained. Some of these paths are more than half a mile long. In places that are sheltered from the sun the roads are above ground, but where they are exposed to the hot rays of the sun the road is, by some species of leaf cutters, tunnelled underground, and it is said to be sometimes carried even under streams. In the nest, in addition to the females and males (at the proper time) there are three or more kinds of workers distinguished by their different sizes and by the work allotted to each. Those of the largest size, which may be five or six times that of the smallest, and which have very big heads, are sometimes called soldiers (similar workers are also found amongst some other kinds of ants) and they do not take part in the ordinary labours of the community, but exercise a kind of general superintendence, as well as defending the nest and their comrades from attack. The medium size workers are employed in cutting and carrying the leaves. These are cut upon the tree into circular pieces about the size of a sixpenny bit, and are stowed away in some of the cavities of the nest. A road crowded with ants, each bearing aloft its piece of leaf, has a very curious appearance, and has suggested for these ants the name of parasol ants. The smallest size of workers remain in the nest and attend to the larvæ and pupæ. What the ants do with the leaves when they have stored them up, is a matter that is still somewhat doubtful. The late Mr. Belt was strongly of the opinion that the leaves were used as manure beds for growing a small white fungus, whose threads may be found ramifying through the masses of leaves, and which was one of the foods of the ants. Mr. McCook, on the other hand, thinks that the ants extract the juices of the leaves and then use the thin dry remains as a kind of paper, with which to construct part of the interior of the nest. He admits that the fungus grows in the leaf masses, but does not think that they are brought in on purpose to grow the fungus. One curious habit of these ants must not be forgotten, and that is the custom they have of closing the doors of the nest at certain hours, a habit which other ants are also said to have. The doorways are carefully filled with bits of twigs, dead leaves and other rubbish, and when thus shut the nest looks like an old and deserted one. The operation of closing the gates is a long and complicated one, and the ants are very careful in seeing that it is properly done.

We must now pass on to a brief consideration of the very different habits of another class of ants, inhabitants of various tropical countries, and variously called from their habits, army ants, driver ants, ants of visitation, chasseur ants, or foraging ants. These ants are not vegetable-feeders, but eat other animals, especially insects, though often creatures of a larger size—even small mammals and birds—fall a prey to them. As by their vast numbers they soon clear out all the food available for them in a locality, these ants are forced to make frequent migrations, and hence have only temporary nests. They march in enormous armies, clearing before them every animal that they can master, and driving even man himself out of their path. Frequently the line of march, purposely or accidentally, embraces houses, to which they are welcomed by the inhabitants on account of the clearance that is made of the numerous cockroaches and other insects, as well as other troublesome inmates, such as rats and mice.

Certain species of these army ants which inhabit tropical America, Mr. Belt considered to be the most intelligent of all the insects of that part of the world. On one occasion he noticed a wide column of them trying to pass along a nearly perpendicular slope of crumbling earth, on which they found great difficulty in obtaining a foot-hold. A number succeeded in retaining their positions, and further strengthened them by laying hold of their neighbours. They then remained in this position, and allowed the column to march securely and easily over their bodies. On another occasion a column was crossing a stream of water by a very narrow branch of a tree, which only permitted them to go in single file. The ants widened the bridge by a number clinging to the sides and to

each other, and this allowed the column to pass over three or four deep. These ants, having no permanent nests, carry their larvæ and pupæ with them when marching. The prey they capture is cut up and carried to the rear of the army to be distributed as food.

Allusion was made above to the fact that ants sometimes make their habitations in suitable parts of living plants. Two instances of this may be shortly noticed. In South America there is a kind of acacia which, from its strong curved spines set in pairs, has received the name of the bull's-horn thorn. When the thorns are first developed, they are soft and filled with a sweet pulp. Now there are two kinds of stinging ants which gnaw holes in the soft thorns, eat all the pulp, and take up their abode in the thorn, which then becomes hard, and affords a very suitable house, the more especially as certain glands on the leaves of the tree secrete a kind of honey, which is the food of the ants. In return the ants protect the tree from the ravages of the leaf-cutting ants, which would otherwise defoliate it. Ants which take up their abode in hollow thorns are also found in other parts of the world. The other instance referred to is that of several kinds of ants which live in the stem of the trumpet-tree, a species of *Cecropia.* This tree has a hollow stem divided into sections at intervals by transverse partitions. The ants make a hole into the tree, and then bore through the partitions one after the other, the cells or chambers thus formed being used to house the eggs, larvæ, and pupæ, each being kept in a different cell. This tree does not provide the ants with food, but they carry into it certain scale-insects that secrete, from a pore on the back, a honey-like fluid which is lapped up by the ants. The scale-insects get their food by sucking the juices of the tree, and live on good terms with the ants. At least three kinds of ants inhabit the trumpet-tree and farm scale-insects, but not more than one kind inhabits a tree at the same time.

Before leaving the subject of the habits of ants, which has necessarily been little more than glanced at, the honey-ants must be noticed. They are American ants, which construct underground nests, but their chief peculiarity is that, in addition to the ordinary inhabitants of an ants' nest, there is a special class, called honey-bearers. These live entirely in the nest, and receive the food collected by the workers, store it up in their globular abdomens, which are capable of great expansion, and regurgitate it in the form of honey when any of their comrades desire to be fed. They are, in fact, merely living honey-bags. In nests opened by Mr. McCook there were from eight to ten chambers, each containing on an average thirty honey-bearers clinging to the roof by their feet (Fig. 4). Another species of honey-ant has been found in Australia.

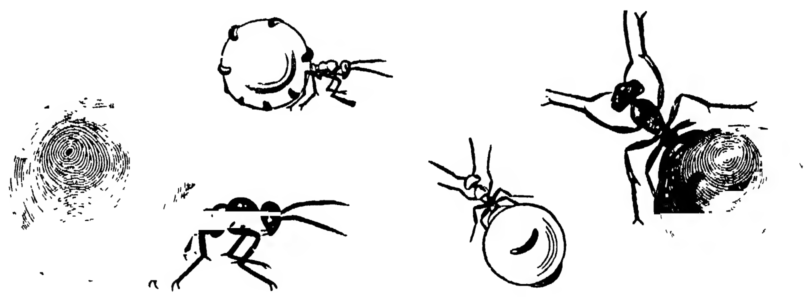


Fig. 4.—Honey-bearers of the Mexican Honey Ants (*Myrmecocystus Mexicanus*), natural size and magnified, viewed from the side and from above.

The examples that have been given of the habits of ants have been enough to show that they are full of interest, and amply repay any attention that can be bestowed on them. We have now to see what conclusions, as to their intelligence and reasoning powers, can be drawn from the result of numerous careful experiments, conducted by Sir John Lubbock,* to which we must refer any one who wishes to study the subject at greater length.

It has long been well known that ants belonging to the same nest are able to recognise each other, even if they have been kept apart for months. On the other hand, an ant of the same species, but belonging to a different nest, is at once recognised as a stranger, and usually treated accordingly—*i.e.*, it is killed. Strange larvæ or pupæ, but belonging to the same species, are, on the contrary, taken care of. But though strange ants are treated as enemies, yet if pupæ be taken from a nest, and entrusted to strangers to rear, and then restored (as adult ants) to their parent nest, they are, in the majority of cases, treated as friends. If, however, they are put in their stranger nurses' nest, they are attacked. Not content with this experiment, Sir John Lubbock put the ants to a more crucial test, and found that ants reared from eggs laid by a female that

* "Journal of the Linnean Society" (Zoology), 1874-5-6-7-9.

had been removed from the nest, were recognised as friends by the ants of the nest that the female had belonged to, though not previously seen by them in any stage of their existence. No explanation has yet been made of this peculiar faculty of ants to recognise their friends and their enemies.

The result of other experiments goes to show that, while ants are by no means destitute of kindness to their friends, yet that hatred of their enemies—that is, of every ant that does not belong to their own nest—is a stronger passion in many species. Another series of experiments were made to ascertain if various colours were recognised by ants, and the conclusions arrived at were that they have the power of recognising colours, but that their sensations of colour must be very different from those produced upon us.

The investigations of many observers have tended to show that ants have the power of communicating information to each other, and thus obtaining assistance in their labours. To test this, many experiments were made, with the result of showing that such powers of communication really exist, and are used by ants.

To test their intelligence in another manner, a number of larvæ were placed in such positions that the ants would—in their anxiety to get at them—either have to drop a very short distance, or to bridge a chasm by pushing a bit of paper a very little way; but the expriment failed to show that they had enough reasoning power to do either, though it would have saved a long and tedious walk by another route. In another case, a drop of only one-third of an inch would have saved an ant from a captivity of twenty-four hours, but the prisoner, though anxious to escape, was too stupid or afraid to venture.

The general result of the experiments and observations shows that ants, though not perhaps gifted with the very great amount of "reasoning" power that some of their enthusiastic admirers have claimed for them, are yet endowed with a much higher degree of intelligence than is possessed by any other insect or articulate animal, surpassing even the bees and the wasps, which, in this respect, come next to them. It has also shown that—as might have been expected—all kinds of ants are not equally intelligent, and that also different individuals and different communities of the same species vary in the degree of intellectual powers which they possess. But the experiments do not enable us to say yet which species of ant is pre-eminently the cleverest. The species that have been subjected to the test belong to temperate countries, and there is reason to suppose that some of the tropical ants are infinitely superior in instinctive ability. In connection with the intellect of ants, it is interesting to note that they are comparatively of recent creation, as they do not make their appearance till the Tertiary period, long after the less intelligent insects, such as beetles and cockroaches, had become abundant.

In concluding this sketch of the habits of some ants, it may be well to remind the reader that many other interesting facts have not been even alluded to.

HOW A BIRD FLIES.

By Dr. Hans Gadow, New Museums, Cambridge.

POETS of all nations, from the earliest times, have sung the "Flight of Birds." Homer continually uses it as a metaphor in his finest passages, and coined that happy phrase, "the winged words," so often used since then: words which raise the soul and waft it over distant lands, and make it "soar" above the clouds in its transcendental "flight."

It is the vague indefiniteness about "flying" which gives the idea and the movement a kind of indescribable charm to the human mind. The peculiar fascination of a river over the dead flat of a lake is that it invites, yet puzzles us to follow it in its free and wanton windings. This is just one of the fascinations which birds possess for us: they fly we know not whither; they are our favourites among animals, but they would have much less attraction if, with all their brilliant plumage and their graceful forms, they were destitute of the power of "flying." This capacity of flying must always render them strange and enviable creatures. Hence we see how men have always striven to invent some method or construct machines by which to imitate them in their flight through the air. It will, therefore, be an interesting subject to consider "How a Bird Flies." By

"flying" we understand the motion of a living animal through the air by help of its wings. A balloon does not fly, in the proper sense of the word; its progress is quite passive, and entirely due to the currents of the air.

Before we take up the theory of flight, we must first consider the construction of birds themselves, though a description of only some parts will be necessary. The head, neck, and feet, for instance, need not be considered. The body of a bird is so formed as to cut through the air with the least possible resistance. Its outlines are free from all angularity and unevenness. This is due to the well-fitting arrangement of all the feathers; they are invariably directed backwards, and thus pressed the more closely to the body as the bird passes through the air. A longitudinal section of the body presents an exact oval, with the thick end at the breast and the smaller toward the tail. The neck and head are either drawn in toward the shoulders or stretched out in front; so also are the feet projected behind or drawn up under the body. Hence pigeons and all singing-birds draw up their feet to prevent resistance from the air; other birds with long feet—as storks and herons, for instance, and most of the swimmers—stretch their feet out parallel behind. They thus balance the long necks which such birds generally have. All birds when in flight strive to bring their centre of gravity to a point midway between the wings; but as the centre of gravity is always behind the shoulders, we find a wonderful arrangement employed to compensate this misproportion, and at the same time to diminish the specific weight of the whole bird.

This is accomplished in two ways. In the first place, the bones of most birds are hollow. There are, however, several exceptions to this rule in the smaller bones; but the larger ones, as the thigh-bone and the fore-arm, are either completely hollow or contain a delicate network of bony tissue, so that the greater part of the bone contains air. The bones are, therefore, as light as possible; whilst in mammals and reptiles the bones are heavier, from their being solid or filled with marrow.

In the second place, in various parts of the body, and especially in the abdomen, there are several pairs of large sacs with thin walls, which can be filled with air, as they are connected by ducts with the lungs. Again, some of the larger bones—as, for instance, that of the fore-arm—have a hole, or *foramen*, as it is called, near the upper end, which is also connected with the lungs, and through which the bone can likewise be filled with air (Fig. 2).

This has been observed in several cases where birds had their wings shattered by shot, which still could breathe even while their mouth and nostrils were held. Suffocation does not take place, as the bird is able to draw air into its lungs through the fractured end of the bone. But let us return to the unwounded bird. The temperature of the blood of birds is higher than that of any other animal, being about one hundred and eight degrees, that of man being ninety-eight degrees. Naturally the air contained in the lungs and all the other cavities of the body acquires the same degree of heat, and as the expansion of the air caused by this warmth increases the size of the air-sacs, the whole body of the bird is made specifically lighter.

Now, what will happen if a bird by a muscular effort fills all the cavities connected with its lungs with such warmed and expanded air?—the air-sacs even in a bird of the size of a pigeon or a crow containing several cubic inches. The whole bird in this state might then be compared to a miniature air-balloon. All this warm air tends to rise; and although it cannot by itself actually lift up the bird—for to lift a bird weighing, say, half a pound, would require many cubic feet of warm air—it at least somewhat diminishes its weight. That this is really the case may be proved by the following simple, and yet, as far as I know, rarely mentioned experiment:—A perfectly tame bird is put on a scale and carefully weighed. When quiet, it weighs, say, if a bird of medium size, five ounces. It is then called from a distance, and as it prepares to fly, lifting its wings a little, *its body swells*, and *before* it takes flight it will be seen that the scale marks a weight distinctly less than that registered before. This is to be accounted for in the following way:—Preparatory to flight it fills its cavities with warm air, which, as explained above, has the effect of diminishing its total weight. Naturally all this goes on with great rapidity, both the getting lighter and starting of the bird succeeding each other without a moment's interval.

A considerable series of experiments made in this way seems to show that the bird regulates the amount of air passed into its air-sacs by the distance it intends to fly, the longer flight needing the greater lightening of the body.

We see, therefore, that the bird really might be likened to a hot-air balloon (a so-called "Montgolfière"). At the same time, too much importance must not be attached to the effect of this heated

air. though, of course, as it lightens the bird somewhat, it takes off a portion of the amount of work which would otherwise fall upon the wings. Again, as the largest air-sacs are situated in the abdomen,

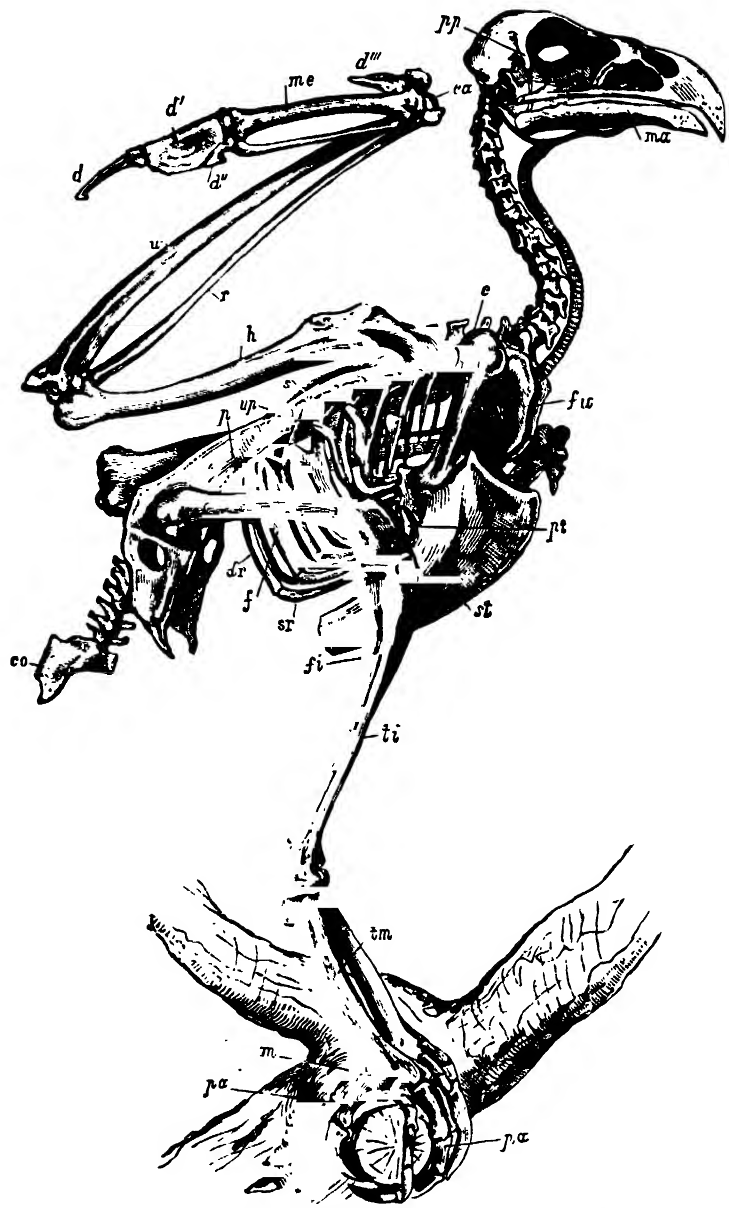


Fig. 1.—Skeleton of an Eagle. (*After Milne-Edwards.*)

p, Pelvis: *c*, Coracoid; *dr*, Dorsal Ribs; *sr*, Sternal Ribs; *up*, Uncinate Processes; *co*, Coccyx; *r*, Radius; *u*, Ulna, *d*, First Phalanx of Chief Digit of the Wing; *d'*, Second Phalanx of Chief Digit of the Wing; *d''*, Phalanges of Lower Digit; *d'''*, Pollex; *ca*, Carpus; *f*, Femur: *fu*, Furcula; *h*, Humerus; *pp*, Postorbital Processes; *tm*, Tarso-metatarsus; *m*, Metatarsus; *ma*, Lower Jaw; *me*, Metacarpus; *s*, Scapula; *pa*, Phalanges of Foot; *fi*, Fibula, *pt*, Patella; *st*, Sternum; *ti*, Tibia.

whenever they are inflated the centre of gravity of the whole bird is shifted forward.

We now come to consider the active apparatus of locomotion, namely, the wings, and to understand them fully we must first study the structure of their bones and muscles.

Fig. 1 shows the skeleton of an eagle, with one of the wings raised. The skeleton of the fore-limb, including the so-called breast and shoulder girdle, consists of the following bones:—

The bony ventral, or belly-wall of the trunk, is formed by the breast-bone, or *sternum*. The body is slightly hollow towards the trunk, and shows on each side of its hinder margin generally one notch or hole. In the middle line of the breast-bone rises, almost at a right angle, a longitudinal crest, the so-called keel, which itself is of a triangular shape, very high, and abruptly rising on the anterior end of the breast-bone, and gradually descending backward. The whole sternum, and especially the keel, bears a direct relation to the amount of labour to be done by the wings, as the principal use of this entire bone is to serve as a foundation to which are attached some of the principal motors of the arm. Consequently the keel is very well-developed, and the body of the sternum is an entire plane, and only little notched in those birds which, like eagles and petrels, are exceedingly good fliers, whilst in birds which do not possess any, or only little, power of flight, like domestic fowls and ostriches, the sternum is either deeply notched or the keel entirely absent. The greatest development of the sternum is seen in humming-birds, which birds, during the greater part of the day, are hovering in front of the flowers, in order to extract with their long slender bills the insects concealed in the cups of the latter.

On its lateral margin the sternum is connected with and fastened to the ribs by the help of several rib-shaped bones (*sternal ribs*), most of the ribs themselves being united with each other by the so-called intercostal ribs. On the anterior margin of the sternum there is lodged in a groove a very strong bone, which is directed upward and outward (*coracoid bone*). Its upper end forms part of the shoulder-joint, where it is connected with three other bones: namely, with a rather flat sabre-shaped bone, extending backwards parallel to the vertebral column (*scapula*, or shoulder-blade); secondly, a rather thin bone, which, uniting with its fellow from the other side, forms the well-known "merry-thought" (*clavicula*, or collar-bone), in front of

the shoulder-girdle, between the neck and anterior end of the keel. Although the clavicula of birds has no connection with the sternum itself, as in man, it is, nevertheless, a true homologue of our collar-bone.

The coracoid bone is of the greatest importance to birds, as it is connected in the shoulder-joint with the humerus, and thus forms the main support of the wing and point of resistance to the fore-arm during the violent and powerful up and down strokes of this organ.

Fig. 2.—Left Humerus of a Red-backed Shrike (*Lanius collurio*). *h*, the Hole through which the Air from out of the Lungs enters the Bone.

The wing itself consists chiefly of the following bones:—The *humerus*, or forearm, loosely attached and not really articulated to the scapula and coracoid, so as to give the wing the utmost possible freedom of motion in almost any direction. Near the upper end of the humerus, on the side which looks towards the trunk, is a hole in this bone, and it is here that the inner cavity of it is in communication with the air-cells of the lungs (Fig. 2).

The other end of the humerus articulates with the *radius* and *ulna*, the two bones composing the lower arm; the ulna is straight and slender, and looks toward the humerus when the wing is closed; the radius, on the other side, is much stronger, and somewhat bent. On its outer surface it bears the smaller series of the quills of the wing (*secondary quills*) (Fig. 3). The bones of the wrist are not well-developed, or else coalesce at an early age with one another. The fingers are generally three in number, the *pollex*, or thumb, being very short, and carrying only a few short quills: the so-called spurious wing. The other fingers, the *index* and the *middle finger*, support the first or greater series of the feathers of the wing: the *primary quills.** These bones form, as it were, the framework of the wing with the feathers attached to them; but in order to expand the latter like a fan, and to move this fan, muscles are needed.

That a plane as large as possible may be brought to press upon the air, the wings are expanded, as said before, in a fan-like form. This is effected, firstly, by an extension of the fingers and other bones of the hand; secondly, by stretching the whole arm, as seen in Fig. 4. The expanded wing has two principal functions of motion—an upward and a downward beat, the latter of which is a down-pressing of the air. This downward motion, however, is not a single beat, but a very complicated action, as the fore and lower arm are at the same time brought forward; again, during the end of the downstroke the wing is somewhat closed

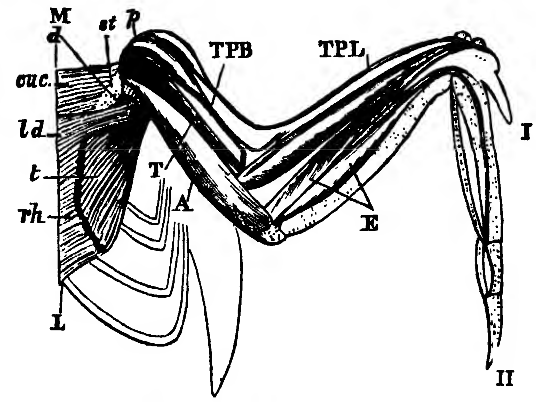


Fig. 3.—Dorsal View of Muscles of Left Wing of Pigeon.

ML, Middle Line of Back; I, Thumb; II, Index Digit; *st*, Scapular Bone; *p*, Great Pectoral Muscle; *d*, Deltoid Muscle; *cuc*, M. cucullaris; *rh*, Rhomboid Muscle; *bd*, Part of Long Muscle of Back (*M. longissimus dorsi*); *t*, Teres, or Suprascapular Muscle; TPB, Short Tensor Muscle of the Skin, between Upper and Lower Arm (*tensor patagii brevis*); TPL, Long Tensor Muscle of Skin between Upper and Lower Arm (*tensor longus patagii*); T, Triceps Muscle; A, Anconeus Muscle; E, Extensors of Hand and Fingers.

and directed backward. To carry out these complex motions many muscles are needed, and there are about thirty employed in the various parts of the wing, too numerous for detailed consideration. We can, therefore, attempt to describe only a few of the principal ones. First, then, let us glance at the back. The space between the scapula

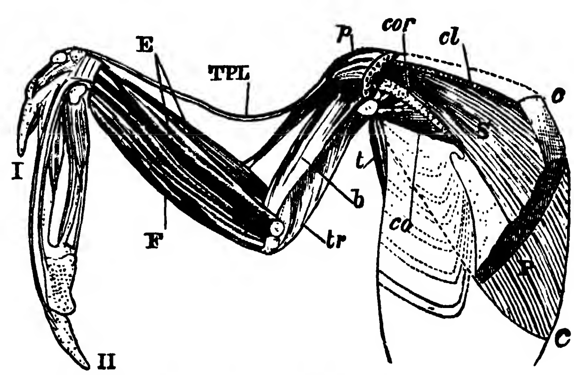


Fig. 4.—Ventral View of Muscles of Left Wing of Pigeon.

I, Thumb; II, Index Finger; P, Great Pectoral Muscle [the greater part of this Muscle has been cut off to show the Sub-clavius Muscle (S), and the M. coracobranchialis (*co*), *cl*, Collar Bone, or Merry-thought; *cor*, Coracoid Bone; *c*, Crest of Breast-bone; *b*, Biceps Muscle; *tr*, Triceps Muscle; *t*, Teres, or Suprascapular Muscle; TPL, Long Tensor Muscle of Skin between Upper and Lower Arm (*tensor longus patagii*); E, Extensor Muscles of Hand and Fingers; F, Flexor Muscles of Hand and Fingers.

and the back-bone is filled by a transverse muscle; the object of this—*M. cucullaris*, as it is called—is to attach the shoulder-girdle to the trunk and to draw it slightly backward. Farther down, this muscle is bordered by another similar one, the *Musculus longissimus dorsi*, which, passing over the scapula

* "A Feather:" "Science for All," Vol. IV., pp. 270 7.

to the upper end of the humerus, draws the latter backward, and thus partially helps to close the wing.

A somewhat triangular muscle, the *M. deltoideus*, goes from the dorsal surface of the scapula to the anterior margin of the upper arm : it lifts and twists the arm.

In front of this muscle arises another one, with short "belly," but very long tendon, which being attached to the edge of the wrist, expands the skin, which fills the angle made by the fore and upper arm when the arm is stretched, and likewise adds strength to the whole wing, and holds it taut.

The largest of all the muscles of the bird are the pectoral muscles. They fill up the entire space between the broad breast-bone and its keel, and are fastened by means of strong tendons to the upper end of the humerus. Their extraordinary development is due to the fact that they have to do a greater amount of work than all the other muscles put together, as they work the downward pressure of the wing, and thus have to support the entire weight of the bird when suspended in the air. The underlying *sub-clavius muscle* has a very complicated function, which can properly only be understood by a careful dissection of those parts. It twists, lifts, and attracts the upper arm, according as the wing is opened or closed.

All the muscles hitherto mentioned are motors of the upper arm. The lower arm is moved by two or three muscles, which spring from the coracoid bone and fore-arm, and are attached by long tendons to the ulna and radius near the elbow-joint. The hinder one (*M. anconeus*) stretches, the anterior one, as seen in Fig. 4, bends the lower arm, or, what is the same thing, draws it towards the humerus.

Similar muscles take their origin from near the elbow-joint, and by long rope-like tendons govern the hand.

This mechanism and the movements of the various parts described comprise all the principal motions of a flying bird, viz., the rising of the body, and its propulsion through the air in a horizontal direction.

In order to explain, however, the astonishing and wonderful movements and turnings which are so admirable in a bird in full flight, we have to consider another portion of the body, namely, the tail. As an illustration of the structure and action of the tail, let us take a bird of prey. In a *hawk* the tail consists of twelve long and broad feathers, the outer and inner webs of which are nearly equal in size. They are supported by the "ploughshare-bone," and can be spread out or shut up like a fan by special muscles. There are also muscles which can raise or depress the tail, and even on occasion turn it obliquely to the right or left.

Every bird, when flying, has to counterbalance, and to reckon with, at least two forces always against it.

Firstly, it has to raise itself into the air, and when risen, to prevent itself from falling down : or, in other words, it has to counterbalance the downward tendency to which it is subjected by the attraction of the earth, a force which perpetually involves to an unsupported body a fall of about sixteen feet in every second.

Secondly, the bird, when progressing in a horizontal direction, has to overcome the resistance of the air, which resistance increases in proportion much more rapidly than the velocity increases, and which of course reaches its maximum when a strong wind blows directly against the bird.

Fig. 5.—Storks in Different Positions. (*Adapted from a Sketch by M.*)

It seems paradoxical to say that just these two forces, which act against a flying bird—viz., its weight and the resistance of the air—are the very things which make its flight possible at all. No bird whatever could fly if it had no weight, and no bird or other animal could move through the air or water—nor could a boat be propelled through the water—if the very same element which is to be cut through did not offer resistance enough to stem the feet or paddles against it, or in our case

to press the wings against the air, and so to act like a pair of levers.

When a bird intends to fly, it first makes itself as light as possible by filling its air-sacs with warm air, as described above; the next thing is to get momentum by starting. This is very easy for a bird sitting on a tree, or, for instance, a swallow starting from the eave of a house. In this case the bird simply lets its body drop or fall, and so gains momentum, which, although at first directed downward according to the law of gravitation, soon after, by the help of its wings and tail, is modified into a forward direction, as we shall see.

It is much more difficult for a bird to start from the flat ground, as in this case it cannot get momentum by a fall. Let us take a stork as an example. He lifts his wings from their ordinary closed position, and throws his body forward, and gives it a sudden impulse by one or more very forcible leaps into the air. Already during the first leap he has expanded his wings to their full extent in a somewhat upward direction, and beats down upon the air with great force. Immediately after there follows another leap, supported by another lifting up and beating down of the wings. Other heavy strokes follow, the legs are stretched out behind, the whole body takes a more horizontal position, and the bird rises obliquely upwards, now only supported by its wings—in brief, it *flies* (Fig. 5).

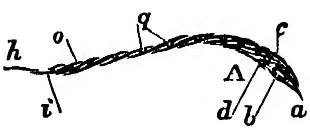


Fig. 6.—Transverse Section of a Wing near tip of Thumb.

I, Anterior, *h*, Hinder, Margin of Wing: *b*, Bone of Thumb; *i*, Inner Web of Quills, underlapping the Outer Web *o*, and the greater part of the next following Quill; A, Concavity of Wing, looking downward. This part of the Wing is, as both upper and under surface, covered with small feathers (upper and under wing coverts, *c*, *d*), ... air;

How the rising part of the flight is effected is easy enough to explain. We must call to mind the form and construction of the wings. When fully spread, each wing exhibits a large plane, the upper surface of which is convex, the under surface concave; the anterior margin is thick and strong, and near the bones, while the hinder margin is thin, flexible, and highly elastic, as it is formed by the primary and secondary quills. These quills underlap each other like tiles of a roof, and in this way the inner, viz., the softer and broader web of one quill, is overlapped by the outer web and the shaft (that is to say, by the stronger and stiff part) of the next following quill. The result of this arrangement must be that, the wing being moved downward, all the quills by the pressure of the air are closely pressed against each other, and prevent the air from passing through. Again, as the wing in a transverse section has the aspect shown in Fig. 6, the beaten air is driven impetuously against the concave and strongest part of the wing into the hole A. It is prevented by the forward and downward motion, and by the form of the anterior margin of the wing from escaping in front of the latter, but can only find an outlet on the hinder margin, and by its escape presses the terminal part of the quills slightly upward. The recoil of these quills, due to their elastic nature, is then transferred to

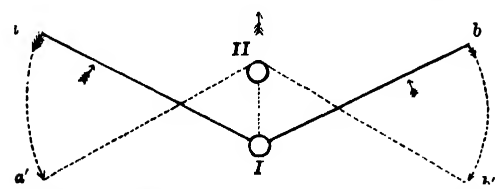


Fig. 7.—Diagram showing the Raising Effect of the Downstroke of the Wings.

I, Position of Bird at beginning of Downstroke of Expanded Wings, I*a* and I*b*. Near the end of Downstroke, the Tip *a* of Right Wing has described the Curve *a a′*, the Left Wing the Curve *b b′*: during this time the Wings were pressing downward upon the air, or, what is the same thing, the beaten air presses against the Wings in the direction of the two small arrows; acting thus as levers, they cause the bird's body to rise from I to II.

their roots, that is, to the active part of the wing, and in this way gives a forward and upward impulse to the bird (Fig. 7).

That this propelling force of the wing, even when not rowing, but simply pressing the air downward, is mainly due to the structure of the quills themselves may easily be proved by the following simple experiment.

If we take one of the long primary quills of an eagle, and try to move it quickly in a vertical direction downwards, preventing it at the same time from turning on its long axis, it will describe a way not vertically but obliquely downward and forward. The air from below presses upward with a much greater force against the broad, thin, and elastic inner web than against the narrow and rigid outer one, and as the strong shaft is much nearer the anterior, or outer, margin of the quill, the whole feather acts like a wedge.

Again, if instead of a single quill you take a whole wing, which has been dried in its expanded form, and if you move it forcibly downward, you will find it extremely difficult, or, if the wing be large enough, simply impossible, to make with your arm an absolute downstroke: the wing will invariably rush in a forward direction.

The whole wing, however, acts (to return to our bird) exactly like a lever with one arm, the fixed point being the shoulder-joint, the free arm

being represented by the long axis of the bird's wing, and consequently causes the bird to rise vertically in the air. (See Fig. 7.) The body of the bird here follows exactly the same principle as a boat with two oars. The air is the water, the two wings are the two oars; but the horizontal motion of the boat and the forward and backward motion of its oars are to be substituted for the vertical upward and downward direction of the bird's wings.

We have now seen that a downstroke of the wings causes the bird's body to rise; but as one single stroke would be insufficient to counteract the gravitation—the falling force, as the rising motion is only the effect of the surplus of upward-directed force over the falling one—the bird requires a perpetual series of downstrokes, or perpetual surpluses. In order to make a new downstroke it has to lift its wings again; but that this upstroke may not have just the opposite result, viz., of pressing the bird down again (as if we were suddenly rowing backwards), is prevented by the wonderful structure of the wing. During the upstroke, naturally, the air rushes against the upper surface of the wing; but this surface is convex, and, what is also of great importance, the air can easily pass through the wing between the feathers from above. Of course during, and because of, the upstroke the bird must fall, but in order to make this fall as short as possible the upstroke takes a much shorter time than the downstroke. This finds a proof in the force with which some pigeons strike their wings over their backs, producing that clapping noise which is familiar to every one.

The resistance which the wing meets with during its upstroke, therefore, is considerably smaller than the resistant power of the air during the downstroke. This difference, the surplus of the latter, has the raising effect.

This force—which, let us say, is equal to a—is used for two purposes. Firstly, to counterbalance the gravity, g, $a—g$ is the surplus left for raising the bird higher with every stroke. If a be equal to g, the result will be that the bird remains in the height once gained. This we can see illustrated by a kestrel hovering in the air, watching the field below, and eagerly looking out for a quarry. In a calm atmosphere it moves its wings rapidly, but with short, quivering strokes, just sufficient to support itself in the air. Here the upward and onward momentum gained by the wing-strokes, minus the force of gravitation, equals 0.

If a wind is blowing, the bird acts, as we shall see further on, like a boy's kite, and saves some muscular exertion. Thus the kestrel, if it wants to remain at the same place in the air, closes its wings somewhat, so as not to offer so great an acting surface to the wind (which would drive it backwards), and moves the wings only very slightly, and can even remain almost motionless for several seconds.

This action of hovering is always a very great task for a bird, and it is only excessively good fliers that can perform it. But there is another organ to be mentioned: namely, the tail. The function of this is often over-estimated, as we frequently find it stated that the tail is the principal organ for directing the flight to the right or left, and that it is generally spoken of as a rudder. That this, however, is the case only to a very limited extent is proved by birds which have lost their tail by accident, and which still preserve their capability of turning. Again, there are many excellent fliers—for instance, the swift—the tail of which is rather poorly developed.

The main function of the tail is that of balancing. Let us take for illustration our hovering kestrel-hawk. If hovering in a perfectly calm atmosphere, the tail of the bird is nearly closed, but if a breeze is blowing, we see that the tail is fully expanded, and, like the whole bird, directly opposed to the wind; it forms the prolongation of the longitudinal axis of the bird, and the whole line from the neck to the tip of the tail makes an angle with the horizontal line. Now, it is clear that the wind rushing against the under surface of the whole body to a great extent presses against this fan, and causes the bird to rise, as the latter is now in the exact position of a boy's kite. The drawing forward of the kite, effected by the boy holding the string, is represented by the gentle motions of the wing, which in this case are so directed, and made with such a force, as to counterbalance the downward tendency to which the bird is subjected by the law of gravity.

Besides this raising effect, the tail has also the power of arresting the progress of the bird by the sudden resistance offered to the wind, and this needs no explanation.

There are, however, several instances in which the tail might really be compared to a rudder, but not, as in a ship, working in a horizontal, but in a vertical direction. To be able to work thus the bird must be in progression. If the tail is fully spread out and sharply inclined downward,

so that it makes an open or even right angle with the long axis of the trunk, the tail then causes a sudden resistance to the air rushing against it, and acts like a rudder, with the effect of pressing the hinder part of the body up and the front part down, and thus changing the horizontal forward motion of the bird into a new and downward one. At the same time, however, the wings will be turned on their axis, so as to present to the air the upper concave surface of the wings, and this, of course, will greatly assist the descent of the bird.

The lifting up of the tail will have the opposite effect, and will help the bird to rise.

Again, as the tail can be depressed in a slightly oblique direction, with one side higher than the other, it thus will help to turn the flight either to the right or to the left.

But as there are many birds which have only a very short, and consequently rather ineffective, tail, and which still make the most beautiful and most astonishing turnings, it is clear that these could not be effected by this organ, and that the bird must produce these evolutions by some other means. Again, as the two wings always beat synchronously, the turning cannot be produced, as

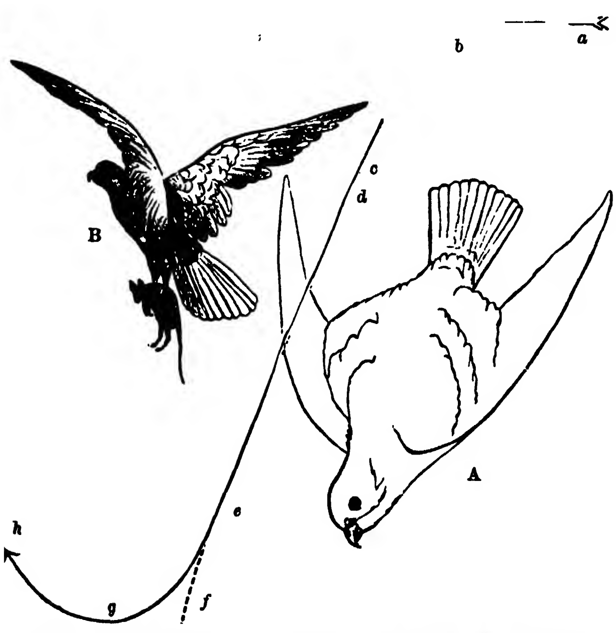


Fig. 8.—Diagram of the Course taken by a Hawk swooping down upon its Prey.

f the Bird at a velocity v; b, Point where the Bird nward, by closing its Wings and depressing its Tail; o which, by its original velocity alone, it would have arrived, time t; g, where it actually is with the assistance of the force of gravity; ef, the way the Bird would descend if, between e and f, the Tail and the Wings did not begin to act again, and to direct the course into a more horizontal one. Thus the Hawk is enabled to seize its prey without arresting its flight, and to rise again at once into the air. A, Position of the Hawk between d and e. B, The Hawk with its Quarry at h.

was often supposed, by beating with one wing alone, whilst the other is at rest. But in all probability the wing on that side to which the bird wants to turn, say to the right, is partially closed—

Fig. 9.—Two Gulls.

A, Showing Position of Wings near end of Downstroke, Wings partly closed, Flight horizontal; B, Position of Wings when Head and Neck are suddenly turned downward and to the right.

the hand with the primary quills being slightly drawn in—and the left wing, as both are making the same number of strokes in a given time, gains a surplus of force over the right one. It gives a greater propelling force to the left side of the body, and therefore turns it round to the right (Figs. 9, 10).

Another way of turning is the inclination of the transversal axis (that from tip to tip of the expanded wings) to the horizon. How the bird shifts its centre of gravity from one side to the other we do not exactly know, but that it actually does so is undoubted. It may be—if it wants to turn to the left—that it allows the air to press against the upper surface of the left wing, by turning the arm slightly on its long axis from above forward and backward, whilst on the other wing the wind presses against its under surface.

No bird gives a better illustration of this kind of turning than the albatross, whose unequalled flight over the stormy waves has supplied a theme for so many voyagers. One of the most scientific accounts is that given by Captain T. W. Hutton, from whom I quote the following lines:—"If he wishes to turn to the right, he bends his head and tail slightly upward, at the same time raising his left side and wing, and lowering the right in proportion to the sharpness of the curve

he wishes to make, the wings being kept quiet the whole time. To such an extent does he do this, that in sweeping round his wings are often pointed in a direction nearly perpendicular to the sea, and

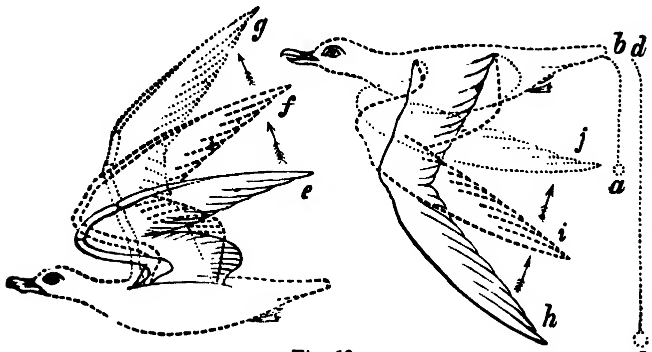


Fig 10.

The two figures show the more or less perpendicular direction of the stroke of the Wing in the flight of the Bird (Gull)—how the Wing is gradually extended as it is elevated (*e f g*)—how it descends as a long lever until it assumes the position indicated by *h*—how it is flexed towards the termination of the downstroke, as shown at *h i j*, to convert it into a short Lever (*a b*), and prepare it for making the upstroke. The difference in the length of the Wing during flexion and extension is indicated by the short and long levers, *a b* and *c d*. (*After Pettigrew.*)

this position of the wings, more or less inclined to the horizon, is seen always and only when the bird is turning."

The rising in a perfectly calm atmosphere will always depend on the amount of force with which the air is pressed upon in a downward direction.

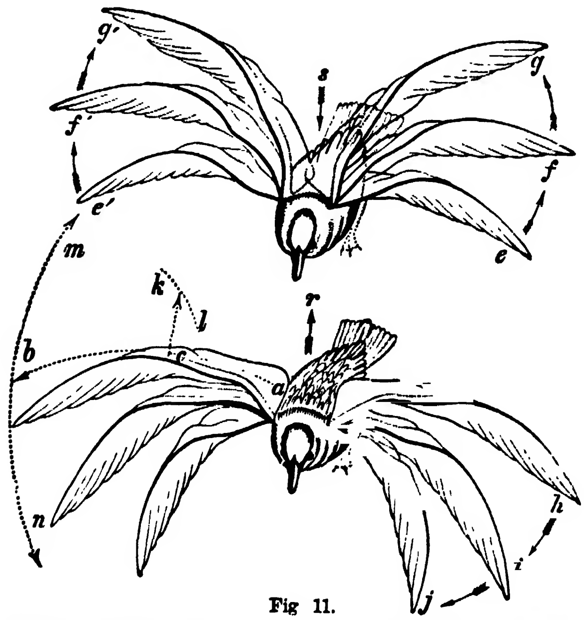


Fig 11.

The same as in Fig. 10, seen from the front. The upper figure shows the Position of the Wings during the Upstroke, during which the body is falling, as indicated by the arrow, *s*. In the lower figure the Wings are seen at three different positions during the Downstroke; the Body of the Bird is rising, as shown by the arrow, *r*. (*After Pettigrew.*)

This, again, may be accomplished in two ways: either by many strokes following in rapid succession in a given time, or by a few but more vigorous strokes. Thus we see that birds with deeply concave and short rounded wings, such as partridges or sparrows, make so many up and down strokes in every second, that we perceive nothing but a whirring motion, and we are utterly incapable of counting the strokes; whilst, on the other hand, an eagle, a gull, or a heron, with excessively long and large wings, makes only a few strokes, perhaps two or three in the same time, as their wings act as long, and therefore more powerful, levers.

So far we have mainly spoken of the motion of the wings in a vertical direction during the up and down stroke. But as these are not the only motions of the wings, let us now inquire into the actual course described by the wings in the air, and into the active propelling force of these organs as far as they resemble oars.

Here it is where we meet with the greatest difficulties, and with entirely irreconcilable dis-

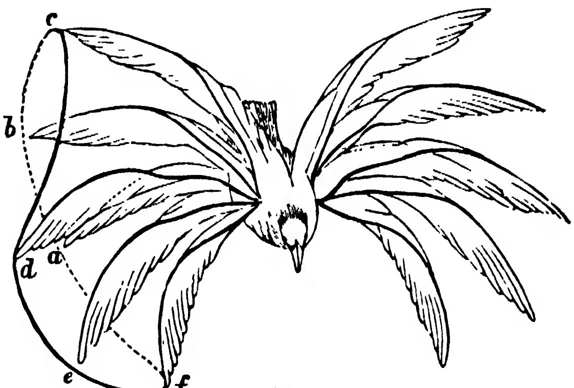


Fig. 12.

A Gull, showing the different Positions of the Wings: three during the Upstroke (slightly drawn, *a b c*), and three during the Downstroke (strongly marked, *d e f*). The curve, *a b c d e f*, shows the way of the tip of the Wing, the thickness of the line indicating the supposed distance of the Points *a f* from the spectator's eye. Thus, at *a* the tip of the Wing has reached its most backward point (so to speak) behind the plane of the paper. From there it gradually rises and reaches the plane of the paper at *c*; from *c* to *d* it is thrown forward and downward, having reached its nearest distance from the eye at *d*, &c. Of course, there would be a closed curve only, if the bird's body were thought motionless and only the wings moving. If the bird were in progression, this irregular but closed curve would be altered into a cycloid one, *see* Fig. 13. (*Adapted from Pettigrew.*)

crepancies of opinions regarding this problem—difficulties which seem to be caused by the fact that different families of birds, and even different species, exhibit great modifications in their mode of flight.

The main propulsive force of birds lies in the primary quills. This is proved by experiments made by M. Marey and Professor Pettigrew. A bird with mutilated primary quills can scarcely fly at all, or its flight is altogether stopped, whilst the clipping off of the secondary quills generally causes but slight inconvenience. At the beginning of the downstroke the wing moves nearly vertically downward, then slightly forward, then downward

again, and more and more backward. In unison with the commencement of the downstroke, as Marey says, "partly from the resistance of the air, partly from the arrangement of the muscles, the wing turns rapidly about its axis. The result of this combined beating, rowing, and screwing movement of the wing is that the bird is forced upward and onward.

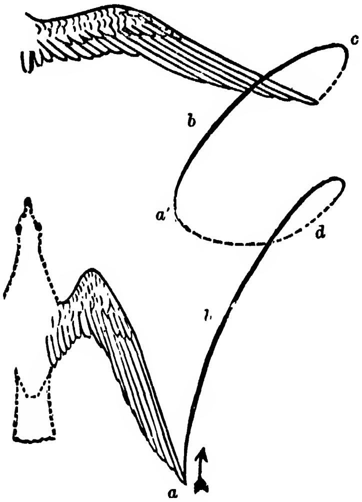


Fig. 13.—Course of Tip of Wing, as seen from above.

troke; a' b' c', Upstroke; the Bird being in progression.

Near the end of the downstroke the wing is slightly bent or closed (Fig. 10). The upstroke begins with a motion first backward, then obliquely upward and forward into its original place again, the under or concave surface being the whole time directed obliquely forward. The tip of the wing thus describes an irregular circle, which, through the progressive motion of the whole bird, is altered into a cycloid curve (Figs. 11, 12), while the humerus describes a real cone, the apex of which lies in the shoulder-joint (Figs. 14, 15). As the wing is somewhat closed, or at least bent, in the wrist, all the primaries being thus directed backward, the tip of the wing is nearer the body at the beginning of the upstroke than at that of the downstroke, when it is generally fully stretched out. Consequently, seen from *above*, the tip of the wing would describe a figure like that shown in Fig. 13.

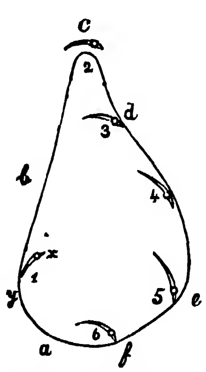


Fig. 14.—Course of Tip of Wing seen from the side, the Bird not being in progression.

a b c, Upstroke: *c d e f*, Downstroke, *c* being the highest elevation of the Tip; 1—6, Transverse Sections through the Wing to show the inclination of the Upper and ... f the ... rizon: *x*, Anterior, *y*, Hinder Margin of Wing.

Another peculiar kind of flight to be mentioned is that of a woodpecker, thrush, or wagtail, or others, which give us an excellent illustration of the way how the momentum gained by falling is used for producing an onward motion. At the same time, it shows very clearly the result of the action of the wings and tail. The wings of such birds are short and rounded; their body has, in ratio to the area of the wings, a rather large weight. The wings, therefore, can only press with little force upon the air, and these birds would have to move their wings as rapidly as partridges. But this is very fatiguing, and costs a great deal of animal heat and labour, and could only be carried on for a short time through a short distance. Thus this kind of progression does pretty well for birds which, like game-birds, pass most of their lives on the ground, and as a rule take to flight only in case of danger; otherwise they prefer to run. But for a bird which has to migrate, and which passes its life in the air or in the trees, this kind of progression would not do.

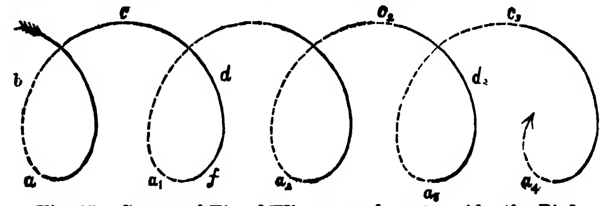


Fig. 15.—Course of Tip of Wing, seen from the side, the Bird being in Progression.

Letters as in previous Fig. The way, *a b c*, of each Cycloid Curve is shorter than the way *c d f*, as the Upstroke is delivered in a considerably shorter time than the Downstroke.

As it is impossible for them to make effective slow strokes with their short wings, they give up, so to speak, the continual motion, as too fatiguing, and make as few strokes as possible. A woodpecker, for instance, with its heavy body, extremely short wings, but rather long and very stiff tail, shows this very clearly (Fig. 16). It begins its flight like other land-birds, rising first by means of rapidly-repeated strokes of the wings. But it is when the bird is in full flight that it exhibits the peculiarities of the latter. In full flight, let us say, it proceeds with a velocity of twenty feet per second. At the point A we see the woodpecker suddenly entirely close its wings, pressing them close to its body. Its course through the air is now defined by two simple forces: first, by its momentum, which drives it in a horizontal direction (twenty feet per second); secondly, by gravitation, which causes it to fall during the first second through a distance of about sixteen feet. These two forces will direct its course according to the parallelogram of forces. At the middle of the first second the bird will be seen at B. Without being subjected to the law of gravitation, it would then be at A′; as the figure shows the falling force having increased the velocity of the bird, the way A B is longer than the way A A′.

A little later the bird will be found at C, and, of course, would soon fall obliquely to the ground if it did not want to reach the tree T. Therefore, after it has fallen through some distance, whilst resting its wings, the bird spreads its tail, and bends this as well as its head and neck up, and lets these parts act like a stern- and bow-rudder. The result of the air rushing against these rudders will be a change in the course of the bird into a curve, with the concave side directed upward, B C D E. The momentum the bird has gained by its fall from A to E, combined with the original momentum of twenty feet, amounts now, perhaps, to thirty feet per second; consequently the air presses against the rudder-like parts with the same force, and this must have a great effect—just as a boat obeys the rudder more quickly the faster it goes. But as naturally the acquired momentum must gradually fail, which failure is mainly due to the resistance of the air, the bird at E renews it by a few new powerful flaps of its wings, and thus reaches the point corresponding to A, let us say, after two seconds and a half. It has, in order to get from the place A to the place F, described the much larger curve, A B C D E F, but with the least possible muscular effort. Then follows another curve like that one described, and so on, till the tree is reached. Or, if we take a wagtail on migration, its way consists of such curves, one following after the other almost *ad infinitum;* but during more than half the time of its flight the wings of such a bird are at rest, and the bird saves a great deal of muscular exertion while on its long, long flight to other climes.

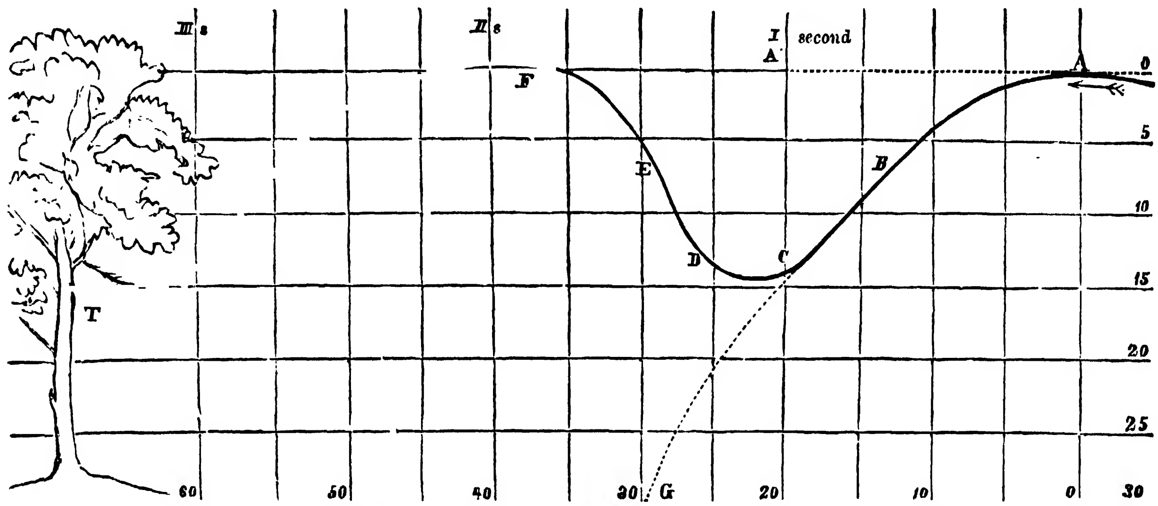


Fig. 16.—Diagram of Flight of a Woodpecker. The Vertical Figures from 0 to 30 Indicate the Height in Feet above the Ground; the Horizontal Numbers on the Ground give the Distance in Feet; the Figures on the Top Line refer to the Time given in Seconds. Thus, it takes the Bird Two Seconds to get from A to F.

THE TELEPHONE AND MICROPHONE.

By Park Benjamin, Ph.D.

THE electric speaking telephone is of too recent production to render any account concerning its origin free from the difficulties and drawbacks always inherent to the recital of contemporaneous history. It is questionable whether any great invention was ever made which has proved such a prolific source of contention in so many diverse respects. No electric apparatus is more free from mechanical complication. It is the only one literally in the hands of the people. The telegraph, the electro-motor, the multifarious devices for electric lighting, the galvanic battery—all in greater or less degree require skilled manipulation and control; but the telephone requires no more operative ability than does the speaking-tube. Yet no human contrivance is more marvellous in its capabilities; and of these there is abundant reason to believe that we have barely approached the fulness of the knowledge that is to come.

The history of the telephone begins with a

semi-prophetic publication made in 1854 by M. Charles Bourseul, who suggested the possibility of transmitting speech by electricity, and even proposed the outline of an apparatus which, though quite inadequate for the purpose, nevertheless pre-figured the fundamental idea that a sound made in one place might be *copied* at a distant place through the agency of the electric current sent over a conducting wire. Following Bourseul came Johann Philipp Reis, a German Professor of Physics, who in 1860 and during the three following years produced several instruments with which he succeeded in transmitting musical sounds, and even occasionally words, by a membrane vibrating against a strip of platinum. No issue in all the great telephone controversy has been more fiercely contested than the question of whether Reis did or did not actually transmit connected speech. The truth probably is that Reis tried to transmit speech, knew the theory which should be followed in devising any apparatus for the purpose, and made contrivances in the hope of succeeding, but never did fully succeed, though there is no doubt that occasionally *words* would flash through his machines, astounding his auditors, and subjecting Reis himself to all the tortures of Tantalus; or that, at times, he heard that curious "upper voice" in his instrument which many experimenting with it in later days have so often remarked, and which just does *not* articulate, but which one cannot help thinking would do so if one's hearing was just a little better. The most singular phenomenon attending Reis's work is the infinitely small distance which separated him from triumphant success and undying honours. Half a turn of a screw perhaps, a weight a little heavier, a spring a little stronger, would have bridged the gap, and the speaking telephone would have been completed fifteen years before it startled the world as the greatest of electrical marvels. But that little difference meant all the vast gulf which separates success from failure.

A year after Reis's death, Alexander Graham Bell, working at this same problem of the electrical transmission of speech, found by accident while experimenting on a multiple telegraph, which he had before invented, that the pulsations in the air due to the human voice in singing and speaking had energy enough of their own to move a little tongue of metal; so that when this tongue was thus vibrated before the pole of an electro-magnet, currents would be caused in the coil of that magnet. He reasoned from this that the currents in the coil would copy or imitate the air-waves due to the sound, and thence that, if he could move something at a distant station by these currents, he might even reproduce at that distant point similar air vibrations, and hence like sounds. He made some machines, but they failed to operate. Many months elapsed before he finally made instruments which would transmit and reproduce speech, although very imperfectly. These he exhibited to a chosen few at the Centennial Exposition at Philadelphia in 1876. But it was not until after that that he finally perfected the instrument which bears his name as the Bell telephone, and which is still generally used as a receiving instrument, though for sending or transmission other instruments are now generally employed. Notwithstanding this latter fact, Professor Bell's claims have been supported in the United States by a patent which has been judicially construed to cover the whole art of transmitting speech by electricity, and an enormously rich and powerful corporation has asserted the monopoly secured by the patent with inflexible persistency. In England, legal obstacles prevented quite such a sweeping control being maintained.

How does the modern telephone talk? Let us look at the apparatus. There are, as we see, two separate contrivances, one of which is apparently a box stationary and fastened to the wall. Into a recess in a door in the front of this box, or transmitter, as it is termed, we talk. This is the telephone's ear. The other contrivance we hold to our ear and it talks to us, and this is called a receiver. It is the telephone's mouth.

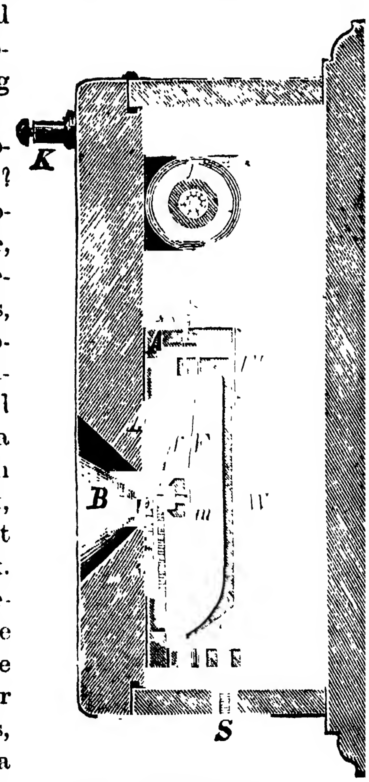


Fig. 1.—Blake's Microphone.

In the United States and Great Britain the transmitter in common use is known as the Blake microphone, after its originator. It is rather an inferior machine as compared with newer forms, but a great

many thousands of such instruments are in operation. If we open the door, we shall see what is represented in Fig. 1, that is, a thin plate of iron marked M, which we seemingly talk against through a little hole; a little platinum cylinder marked *p*, which is held by a spring against this plate, or diaphragm, as it is called; and finally, a heavy button of brass marked *m*, in front of which is a piece of smooth hard carbon which bears against the little cylinder. The brass button is also held by a spring. There are, besides, movable supports and adjusting screws which, as we can readily see, must serve to press the diaphragm and the little cylinder and the carbon-faced button together.

Now the little platinum cylinder and the button which rests in loose contact with the cylinder, are the most important parts of the instrument. In Fig. 2 they are sketched separately,

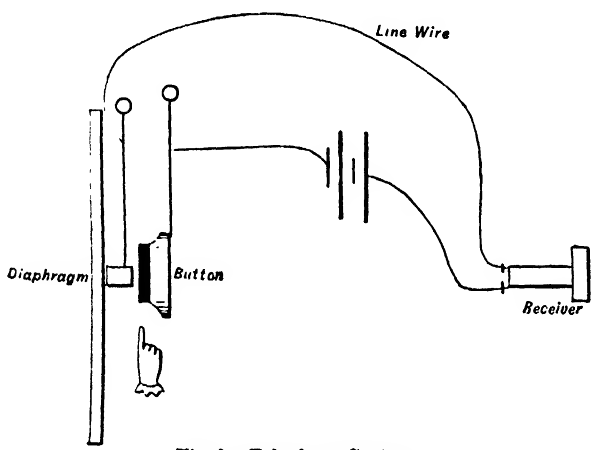


Fig. 2.—Telephone System.

and we have added to them the usual conventional representation of a galvanic battery and a circuit wire. The current from this battery goes first to the spring which supports the little platinum cylinder, then to the cylinder itself, then over to the carbon on the brass button and along the spring that carries the button, and so back to the battery. We have also placed a diaphragm or sound-receiving plate in front of, and touching, the cylinder, and we have put the wire from the battery in connection with a receiver, at which we suppose some one else is listening, and the construction of which we shall explain presently.

Now we are ready to transmit speech, because in Fig. 2 we have everything that is necessary to enable us to do so. Indeed, with just these simple parts put together—and the actual Blake transmitter merely adds some convenient adjusting devices—we can send speech perfectly well. Here is a wire with an electrical current running over it; and observe that the same current goes through the loose contact from cylinder to button; note, further, that bearing against this cylinder is the diaphragm, to which, however, no current goes. The whole wonderful work of this instrument is done at, and by, that little loose joint, that point of loose contact between the cylinder and button. The forefinger of the hand in Fig. 2 points out the exact place, and so we reach one of the most singular and curious facts involved in the electrical transmission of speech.

A current of electricity in a wire behaves very much like a current of water in a pipe. If the pipe is reduced in size, or if obstructions of any sort are put in it, the water current is impeded, and encounters resistance to its flow. An electrical current may meet resistance in much the same way, and the greater this resistance is, the less becomes the strength of the current; consequently, if more resistance be interposed at one time than another, the current will be weaker at intervals. Certain substances, such as the metals, conduct electricity much better than other substances. Carbon, for example, while conducting, nevertheless offers considerable resistance, and an air space between the separated ends of a conductor presents so much resistance that only the most powerful batteries can drive a current through an air space a quarter of an inch long. Between the contact-points of the loose joint in a telephone transmitter there is a film of air, and, besides this, the material of one or both of the parts of the joint is usually carbon, so that the joint forms a place of high resistance to the current. If, however, the parts of the joint are brought more closely together, the resistance to the current is diminished; while if they are allowed to move away from one another, the resistance is increased. In the transmitter these parts never separate; they simply move toward or from one another over distances too small for human computation, but nevertheless large enough to produce decided variations in the strength of a current passing through them. Let us illustrate this again by a water current. Suppose we have a tank of water, from which extends an india-rubber tube, through which the water flows; clearly by simply squeezing the tube we diminish its sectional area, and so less water can run through. We accomplish the same thing in turning a stop-cock. The loose joint acts very like a valve or stop-cock

A

to the electrical flow, and it gives us a means of varying the strength of a current at will.

But there is one very remarkable difference between working the water valve and the electrical valve. Talking to a water valve will hardly alter the water flow, but talking to the electrical valve will do so with delicacy; this has next to be explained. Sound is due to vibrations or waves produced in the air. The strings of a violin or the human vocal chords, in vibrating, set the air in motion, in actual waves, in which the air particles swing to and fro, just as do the water particles forming a wave of the sea. The sea waves, we know, may have immense power, tossing the heaviest vessels like egg-shells, and beating down the strong walls and bulkheads. The same power resides in air waves. The explosion of a dynamite factory or powder magazine often produces air waves having energy enough to level adjacent buildings, crack walls, and do other damage for miles around. Of course, the little air waves produced by our voices are infinitely weak by comparison, and yet they have abundant strength to work our electrical valve. All that we have to do is to direct them upon it, and they will move its parts in unison with themselves, pressing them together when they dash upon them, allowing them to move in the opposite direction when they recede, just as the surf coming on the seashore hurls the loose stones on the shore together, and then, flowing back, scatters them again.

We can form no conception of the infinite smallness of the sound wave, and of the infinite delicacy of the electrical stop-cock which responds to the changes in the character of the movements of the air particles. Yet the water analogy will help us a little. Waves on the ocean vary in height and vary in length, and the ripples on the surface of one big wave may be longer and higher than the ripples on the surface of another big wave. In sound waves, the louder the sound the higher, so to speak, is the wave; the shriller the sound, the shorter the wave; and finally, what is called the timbre or quality of the sound—that peculiar characteristic which distinguishes the voice of a man from the voice of a child, articulate speech from inarticulate noises, the tone of a violin from that of a flute—is due to the minute ripples on the large sound waves. Now, not only must the electrical stop-cock respond to the differences in loudness of sound, and to the differences in frequency of the sounds, but to these infinitely minute, subsidiary, superimposed waves. For example, the sound due to the note an octave above middle C of the musical scale has 512 vibrations in a second, and there may be imposed on this, by a woman's voice in singing, as many as 22,000 tiny "quality" or timbre vibrations in the same time. Yet so marvellously delicate is this electrical stop-cock of a loose contact, that it will exactly turn off and on the current more or less, in response to every one of these infinitely small movements of the air, and it will thus apparently set the current vibrating through the wire in exactly the same way.

The sensitiveness of the microphone or resistance-transmitter depends wholly upon the delicacy of the contact at the parts of the loose joint. Fig. 3

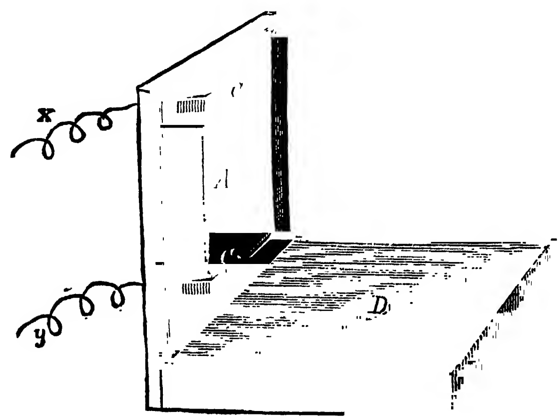


Fig 3.

represents one of the earliest, and, at the same time, one of the most sensitive forms of these instruments. D is a platform on which is erected a vertical board, A. To this board are affixed two carbon blocks, C C, between which the carbon rod A is placed so that it rests upon the lower block by its own weight. The current is conducted through the blocks and rod by the wires X *y*. When a telephone receiver is connected in circuit with the instrument, sounds ordinarily wholly inaudible to the ear can be clearly heard. An even simpler microphone can be made of three nails,

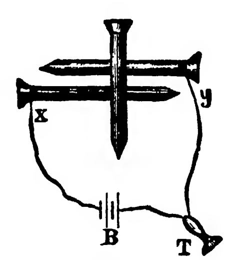


Fig. 4.

disposed as shown in Fig. 4, and connected in circuit with a battery, B, and telephone receiver, T. Any loose joint between substances through which a current of electricity can pass, may thus act as a transmitting telephone. No matter how the contact-pieces are made, no matter how they are supported, so long as they are really held in

loose contact, they can be made to transmit speech. Two silver coins, one laid on the other, two bits of coke or coal, the loosely-connected ends of a stretched wire, a pinch of powdered coke, a handful of shot: any of these is a telephone transmitter or microphone. These simple devices were first systematically studied and made public by Professor Hughes in 1878. Of course great differences in efficiency follow nice adjustments, and the use of devices for that purpose, but essentially nothing more than any one of the above examples is needed.*

Now we can begin to see how the telephone transmitter works. It makes the electrical current *vibrate* just like the sounding air. It makes waves in the current corresponding exactly to the air waves, and just as the sea transmits the wave movement on and on, perhaps for hundreds of miles from the point at which it starts until the last wave breaks on the shore, so the electrical waves emanating from the vibrating diaphragm are transmitted through the wire until they reach their destination. And thus we produce at the far end of our wire, waves of electricity corresponding with the air waves made by our voice in speaking.

But we cannot hear these *electrical* waves. The end of the wire put to our ear will reveal nothing. The ear can take cognisance only of

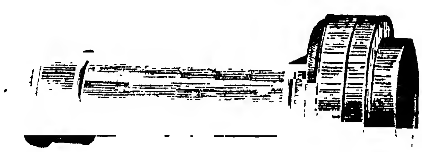


Fig. 5.—Bell's Telephone.

sound waves in air. This brings us to the receiver, which is easily recognised from Figs. 5 and 6. This is, in fact, a machine for transforming electrical waves into sound waves, and as such is the converse of the transmitter, which, as we have seen, changes sound waves into electrical waves. In Fig. 6 is represented a receiver cut in two lengthwise, so as to exhibit its inner mechanism. First, there is a long bar of iron, *m*, which may or may not be permanently magnetised. On

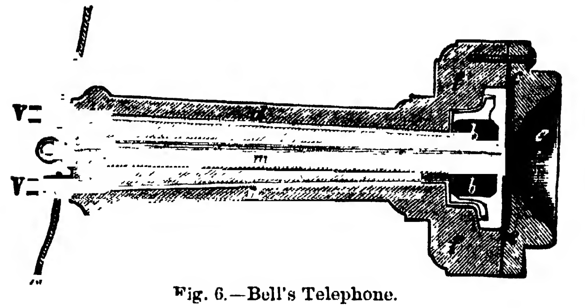


Fig. 6.—Bell's Telephone.

one end of this bar is a coil, *b*, of carefully insulated wire, and in front of the coil is arranged a thin iron plate, *c*, which, however, touches neither the coil nor the inclosed bar, although it is set very close to the end of the latter. To the end of the wire coil is attached the wires *d d*, leading from the binding-screws V V, to which are connected the line wire from the transmitter and the wire leading to the ground, so as to complete the electrical circuit through the instruments. Now we have a complete telephone system. When the current comes over the wire, it runs through the coil around the iron bar or core, and in so doing it makes the bar a magnet. When the current stops, the receiver-core is no longer a magnet. When the current gets stronger, the bar is a stronger magnet; and when the current weakens, the bar is a weaker magnet. But, as has already been explained, our current is being varied in strength in a way exactly corresponding to the sound waves produced by the voice; and as the current controls the magnet, the result will be that the magnet will vary in attractive strength correspondingly with the current. In front of our magnet is the thin iron plate, held at its edges like a drum, and this the magnet, as it strengthens and weakens, can attract and release, and so this plate is set in vibration exactly conformably to the variations in strength of the magnet.

Probably no more beautiful illustration of the convertibility of one form of energy into another could be suggested than is here afforded in the telephone. The mechanical movement of the air particles, set vibrating and causing sound, produces vibrations in an electric current; this in turn produces variations in the strength of a magnet, and the magnet moves a metal plate, and the metal plate sets the air in motion, and the air in motion at the far end of the line produces a sound just the

* With all the telephone transmitters at the present time induction coils are used. How induction coils are made, and their general use, the reader will find described in the paper on the "Wonders of Induction." The induction coil of the Blake transmitter is shown at J in Fig. 1. The contact-pieces and battery are connected in the primary circuit, and the secondary wire of the coil leads to the line. The principal object is to increase the pressure of the modified current, so that it may overcome the resistance due to long lines, and thus enable speech to be transmitted over greater distances than if the direct battery current were used.

same as that originated at the sending end of the line. This is how speech is transmitted and reproduced by electricity on about all the commercial lines in the world. The instruments vary, as we shall see hereafter, considerably in constructive detail, but their general features are, with few exceptions, all alike.

The transmitter which we have described is known as the variable resistance instrument, or microphone. Before this was made public, speech was transmitted telephonically by the same instrument which we now use as a receiver. While this apparatus operates to convert sound vibrations into electrical vibrations, it does so in an entirely different manner from the transmitter described. When a magnet is moved to and fro in and in front of a coil of wire, a current of electricity will be set up in that coil, the direction and strength of which will be dependent upon the character of the magnet's motion; and on this principle dynamos for producing powerful electrical currents are constructed. The same thing is true if the magnet be stationary with a coil fixed upon it, and a piece of iron be moved in front of the coil—again currents will be produced in the coil. This is what happens in the magneto-telephone, as it is called; which, in fact, is virtually a little dynamo machine. When the diaphragm or plate is set in vibration, it produces currents in the coil surrounding the magnet, and as the plate vibrates correspondingly to the sound-waves produced by the voice, so the current produced will vibrate. We rotate the armature of a great dynamo to produce the current for electric lighting by a steam-engine, and as we want a very uniform and steady current, we carefully control our engine and regulate the dynamo to that end, otherwise the electric lights would flicker and be disagreeable. In the magneto-telephone, on the other hand, we produce the current by moving the plate or armature to and fro by the air disturbed by the voice, and thus we make a current varying with every minute change in the air movement.

The magneto-telephone may be used with or without a battery. If used without a battery, its core must be a magnet, and in such case the only currents which go over the line are those generated in the instrument itself. If a battery is used, then the current therefrom flows constantly over the line, and the currents generated in the telephone are superimposed on the main or battery current. The only use of the battery in such case is to convert the core of the telephone into a magnet, if it is not already one. Fig. 7 represents diagrammatically a magneto-transmitter and receiver coupled in circuit. At N and S are the cores of the instru

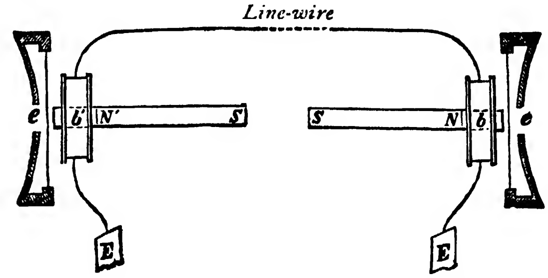


Fig. 7.—Diagram of Transmitter and Receiver.

ments, *b* and *b'* are the coils, and at *e* are the mouth or ear pieces.

We find, therefore, that there are two principal forms of telephone-transmitter: that which works by a resistance put in the way of a steady current and modified by the voice, and that which works by currents generated in the core of an electromagnet by a plate of iron vibrated by the voice in front of the pole of the magnet. The latter form is not so much used as the former, because it is not capable of transmitting such strong currents.

To give even the briefest sort of description of the numerous telephones which have been invented would extend this paper far beyond possible limits. The changes made in the receiver or magneto-telephone have been few and comparatively unimportant; but of the resistance-varying transmitter, there are hundreds of modifications, until it appears as if there remains little room for the exercise of further ingenuity. In some instruments the contact-pieces, as in the Blake transmitter already described, take the shape of small blocks or masses of carbon, both pieces being of carbon, or one of carbon and the other of metal. These are supported in contact by springs, or simply allowed to rest one against the other by gravity. Then, in other forms, the contact-pieces are multiplied, or even made infinitely numerous, by making the carbon into a mass of fine granules, almost a powder, through which the current is conducted. These powdered carbon transmitters are wonderfully sensitive; with a strong

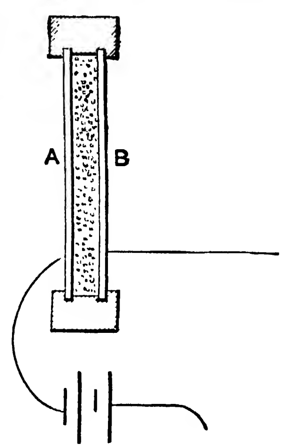


Fig. 8.—Powdered Carbon Transmitter.

current they will cause speech to be reproduced in a good receiver, so that it can be heard perhaps fifteen or twenty feet away from the instrument. The carbon is arranged simply between two conducting plates, A B, one of which is a vibrating diaphragm, so that the essential features of the entire instrument are shown in Fig. 8. An instrument of this kind will take speech vibrations even from the outside of the body of the speaker; and one can indulge in the odd experience of talking with his Adam's apple, or his breast-bone, or the top of his head. Crossley's microphone, which has come into limited employment in Europe, is represented in Fig. 9.

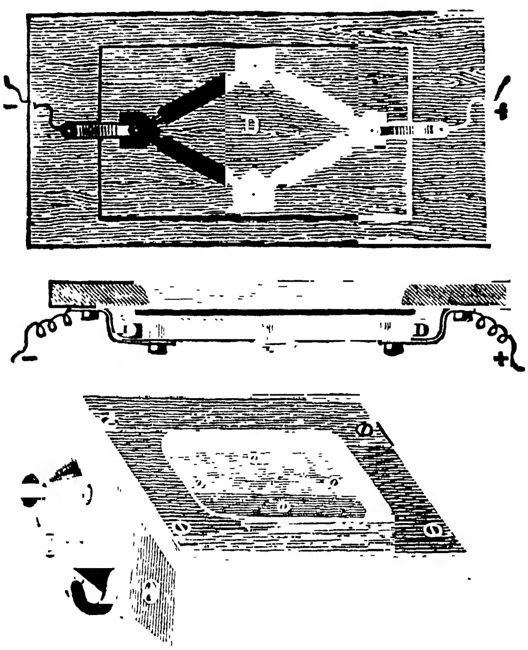


Fig. 9 --Crossley's Transmitter.

This instrument has four carbon rods, which make loose contact at their ends with carbon blocks; the rods and blocks are supported upon a slab of wood, D, which serves as a diaphragm and as a cover for the desk-shaped box.

There are certain forms of receivers which are widely different from that already described; such, for example, is the Dolbear condenser-receiver, which is represented in Fig. 10. This consists simply of two metallic discs, supported in the case of the instrument so as to be very close together, but not in contact. One disc is pressed upon by a screw at its middle, and is thus prevented from vibrating; the other is free to vibrate. One of these discs is connected to line, and the other to earth. As the varying currents flow into and out of this condenser, the two discs attract one another more or less strongly, and thereby vibrations are set up which correspond to the vibrations of the original sounds.

Another curious receiver, Fig. 11, is that invented by Mr. Edison, in which there is a cylinder,

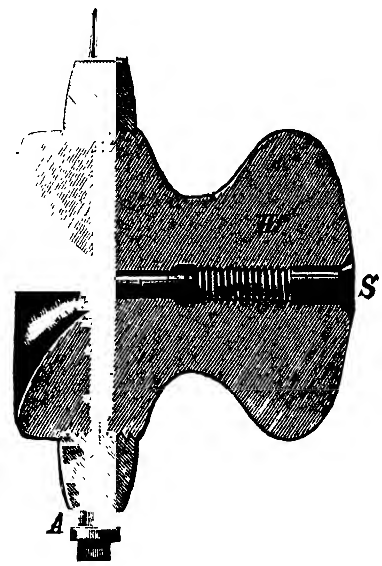


Fig. 10.—Dolbear's Receiver.

A, composed mainly of chalk, against which rests a platinum strip, a, which is also secured to a diaphragm, D. The circuit passes through cylinder and strip, and the cylinder is rotated at uniform speed. The friction between cylinder and strip causes the diaphragm to be drawn inwards — that is, towards the cylinder—so that the diaphragm is thus brought to a certain position. When a current passes through the instrument the friction of the strip and cylinder is reduced, and the diaphragm flies back by its own elasticity. As the variations in friction correspond to the variations in the strength of the current coming to the instrument, the diaphragm is thus caused to vibrate so as to reproduce speech. This apparatus gives loud sounds, but it is by no means reliable in operation, and not at all adapted for practical every-day use.

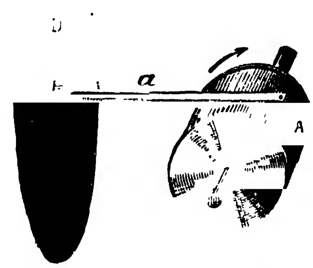


Fig. 11.—Edison's Loud Receiver.

Although, as we have said, the telephone receiver as commonly used consists of a core, a coil on the end, and a diaphragm in front of the coil,

and all of these parts are necessary for practical work, it is an odd fact that speech can be heard without any one of them. We can remove the diaphragm, when sound will be heard from the coil and core. We can leave off the coil, connecting the ends of the wire simply to a rod of iron supported at one extremity, and hear the rod talk. We can abolish the rod and fasten our wires to a condenser made of sheets of tin-foil separated by paraffined paper or mica, and hear sounds very clearly coming from this apparatus. And finally, one of the most curious telephonic experiments ever made was that performed by M. Giltay at the laboratory of the School of Physics, in Paris, when he made people's hands speak. He arranged the apparatus as represented in the diagram Fig.

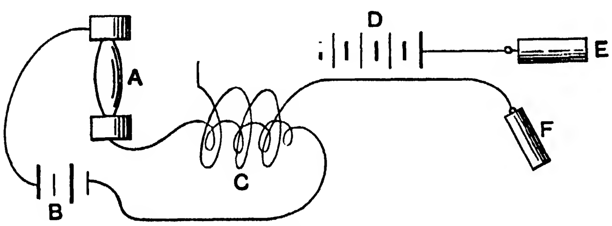


Fig. 12.—Giltay's Arrangement.

12, in which A is a microphone or resistance-transmitter, B a battery, C an induction coil, and D another battery in the secondary circuit of the coil. To the ends of the secondary circuit wire were

Fig. 13.—Giltay's Human Telephone.

connected metal handles, E and F. Two persons hold each one of the handles, and each person applies his disengaged hand to the ear of a third person, as shown in Fig. 13, when the third person hears the transmitted speech. It is even possible to make a sort of telephonic chain, enabling five or six persons to hear at once—No. 1 putting his hand to the ear of No. 2, No. 2 his hand to the ear of No. 3, and so on to the last person who closes the circuit by holding one of the handles, the other handle being held by the first person of the series.

A volume might be filled with the recital of other curious phenomena of the telephone, to which we can refer only briefly here. It is so wonderfully sensitive that it is affected even by the natural electric currents existing in the human muscles. M. Boudet, of Paris, has used the instrument as a means of hearing the working of the muscles in certain paralytic and nervous ailments. The microphone has also proved to be a stethoscope capable of revealing murmurs in the circulation which cannot be detected by the ordinary apparatus. In connection with the induction balance, the telephone has been used to reveal the presence of hidden metallic bodies, to test the conductivity of different metals, and even to detect counterfeit coins. It has been employed to hear the mutterings of earthquakes and of volcanoes before eruption. It has served as a communication from earth to balloons. It allows watchmen on the surface to listen to the operation of the pumps in deep mines, and to communicate with other mines. It renders submarine diving far less perilous, inasmuch as it enables the diver on the sea-bottom freely to converse with the men attending the air-pumps and life-lines. Buried in the earth, it has proved an efficient means of detecting subterranean springs, the gurgle of which is plainly heard. In all wars of the future it will play an active part. Hidden in the ground around fortifications and camps, it will reveal the footfalls of an approaching enemy, and so guard against surprise. It will serve as a means of communication from main bodies of troops to pickets and skirmish line. It will reveal the presence of submarine mines and the approach of movable torpedoes. Experiments are even in progress whereby some success has been attained in telephoning through water between vessels at sea.

To what distance the telephone will transmit speech is not a settled matter, on account of the many disturbing causes—such as leakage, retardation, and induction—which tend to impair the delicate electric vibrations. In the United States overland lines, speech has been successfully sent between Chicago and New York, a distance of about 900 miles. Tests on artificial lines representing

the Atlantic Cable show that probably the maximum distance on submarine wires over which words can be distinguished does not exceed 150 miles. Conversation has, however, been successfully maintained in Europe between Brussels and Dover, and between Holyhead and Dublin. Telephoning without wires may, perhaps, ultimately be accomplished. Telephones have been fixed upon a wire passing from the ground floor to the top floor of a large building, the gas-pipes being used as a return, and the Morse signals sent from a telegraphic office 250 yards away have been distinctly read. There are several cases on record of telephone circuits *miles away* from any telegraph wires, but in line with the earth terminals, picking up telegraphic signals by induction.

And yet the instrument which accomplishes all these and many other wonderful results, employs forces of a delicacy of which we can form no adequate idea. The total path of the vibrating air particle is perhaps one-millionth of an inch in length; its period (half-vibration) is as short as one four-hundredth of a second in many instances. Within this small limit of time and space, lie packed all the variations which distinguish from each other all words of all languages. The strength of the current available in the magneto instruments has been reckoned at a ten-millionth of an ampere. The minuteness of these distinctions seems almost to defy computation and statement; and yet the telephone acts by taking note of them and reproducing them.

HEAT AS A MOTIVE POWER.

By W. D. Scott-Moncrieff, C.E.

In considering heat-power,* it was necessary to go back upon previous illustrations, in order to make the subject clear. In the same way, the recollection of the reader is now recalled to the papers upon Power and Work in order to understand the relationship which exists between heat-power and heat-work, or heat as potential or kinetic energy. There are so many media through which heat can be converted from one of these forms of force into another that it would be quite beyond the scope of a single paper to explain them all.

The general aspect of the subject of heat as a form of force essentially similar if not identical with other forces which have their origin in motion, must be held clearly in the mind of the reader, and his attention must at the same time be specially directed to that side of heat force which is exhibited when heat is in the state of passing from heat into the visible motion of solid substances moving against opposing forces as in the case of the moving parts of a machine. In other words, the theory of a hot body being that of a mass whose particles are in violent movement, must stand by itself as belonging to the aspect of heat as potential energy; and we must now confine our attention to the phenomena which attend the disappearance of heat as heat, and its re-appearance as kinetic energy, or work.

The effects of heat upon a permanent gas, such as common air, in adding to its volume or its pressure, and a consideration of how the increase in the one of these effects is followed by an exactly corresponding decrease in the other, has already occupied a considerable portion of the paper upon heat-power. It would not be a difficult task to go on using the phenomena of perfect gases under increments of temperature, as a means of illustrating the mode in which heat can be so employed as to disappear and be restored as work. It would even be clearer, from a purely theoretical or scientific point of view, to continue to make use of these illustrations. Practically, in a paper on heat-work, however, it will be better to turn our thoughts to the great every-day medium for converting heat into kinetic energy we discover in the steam-engine, which performs such a vast variety of useful work among the innumerable industries of modern life.

In dealing with steam as a means of illustration, the first point to be noticed is that in the steam itself we are dealing with what may be looked upon, for all practical purposes, as a permanent gas *within certain limits of temperature*, and that therefore the phenomena which attend its conversion into work are the same as in the case of common air, which we have already considered, always remembering that the physical comparison only holds good *within the limit of temperature*, below which the steam ceases to be of the nature of a permanent gas, or even of an elastic fluid, and becomes liquid

* "Science for All," Vol. IV., p. 230; Vol. III., p. 249.

as in the case of steam condensing into water. The other important distinction between air and steam is that the former comes to us as an elastic fluid ready to our hands, whereas the other requires to have a large quantity of heat expended upon it before it becomes a medium for the conversion of the heat into work at all. In the case, then, of the vapour of water, we must first inquire how much heat is necessary in order to raise it to the position of a permanent gas.

The normal condition of water may be looked upon not as in the fluid, but the solid state. That is to say, that if we were deprived of the heat of the sun, or that quantity of heat which is necessary to keep water liquid, we would have to start with ice, and the first use to which we would have to put our heat would be to convert it from the solid into the fluid state. Now the amount of heat which is required for this operation is one of the most constant quantities that can well be conceived of, and the invariable character of the phenomena attending the melting of ice affords a satisfactory basis for numerical calculations with regard to temperature. As arithmetical illustrations are both simple and satisfactory, we cannot do better than adopt them in the present case.

The heat unit in this country, already frequently spoken of, is taken from the quantity of heat required to raise the temperature of 1 lb. of water at 39° Fahr. at the level of the sea 1° Fahr. The mechanical equivalent of this heat is the amount of energy necessary to raise 772 lbs. weight one foot high. In other words, the amount of potential energy represented by the quantity of heat required to raise a pound of water one degree is the force-equivalent of the kinetic energy represented by raising 772 lbs. through a height of one foot. Now we will take the case of a pound of water, and see what happens if we first convert it from the solid state of ice into the liquid condition of water, and go on adding heat until it is converted into steam, then treating the steam as if it were an elastic fluid, like air, expanding it as explained in the last paper on heat-power, converting all the power available into kinetic energy, and finding out the net number of heat units turned into useful work as compared with the number we originally started with.

Let us, for convenience sake, take 5,000 heat units as the total quantity available, either from a certain weight of coal burning in contact with the water, or from any other substance communicating heat by combustion to the same extent. It is quite certain that no useful work can be obtained from the ice, so we must first convert it into liquid water. This will absorb 144 heat units before we go any further, and the volume of the pound of water will have been slightly changed in consequence. The exact alteration of volume amounts to the difference between 1· and 1·0909. Now we have only 4,856 heat units left, and the next use to which we must put our store of heat-energy is to convert the water into steam, for unless we made a gravity-engine of the fluid, and raised it to a great height, as explained in the paper on the Water Wheel, it would be as impossible to make use of it as a medium for doing work as it was in the case of the solid ice. Now any one who had such a limited supply of power as the quantity we have taken to start with, and who had a great deal to do with it, would be much disappointed if he discovered, for the first time, what a great price he had to pay for his steam. As it is, his supply has already been reduced to 4,856 heat units, and now, to convert the water into steam, he has to pay, first, 182 of his heat units to raise it to the boiling-point (212° Fahr.), and then 965 units to convert it into steam, leaving him only with the balance of 3,709 for conversion into useful work. Now comes the question how he is best to apply the balance. Turning back to the paper on heat-power he will find an explanation of the best way of dealing with it, together with the reasons that make a high pressure the most economical method. He cannot do better than make the vessel for containing the steam as strong as possible, and expend every heat unit at his disposal, not in converting more water into steam, but in, first of all, raising the steam he has obtained from the original pound to the highest temperature and pressure which practice has proved to be capable of being taken advantage of in a properly-constructed steam-engine. First of all he should cover the vessel or boiler containing the steam with the best non-conducting substance he can obtain, in order to prevent the heat from passing away by radiation and convection into the surrounding atmosphere, and then treat the steam as much as possible as if it were a permanent gas, such as common air. Before going on to see what the effect will be of simply adding heat to the steam, it will be well to consider how it is that so many heat units have been absorbed without the possibility of converting them into useful work.

It has already been shown how heat that has disappeared from the working medium of a prime-mover appears in some other form of force or energy. In the apparent total loss of the 1,291 heat units,

however, we discover the equivalent nowhere but in the transformations which have taken place in the substance we are dealing with—first, the conversion of ice into water, and next the conversion of water into steam. These equivalents are, as the reader is already aware, spoken of as the latent heat of the respective substances, and it may be described as that portion of the communicated heat which is incapable of conversion into kinetic energy or work. In the case of ice and water, it is the heat price we have to pay for the substance we use as our work medium called steam. Fig. 1 will convey graphically to the mind of the reader what actually occurs :— The base line represents the number of heat units required to effect the operation, of converting the ice into water, and, afterwards, the water into steam. First of all, as the specific heat of ice is about 0·5, or half that of water, in order to raise its temperature from 0° Fahr. to 32°, sixteen heat units will be absorbed, and the volume of the total quantity being altered in the ratio of 1·0909 to 1· the water-line will vary from the ice-line to this extent. In the words of Professor Clerk Maxwell, the ice now begins to melt, the temperature remains constant at 32° Fahr., but the volume of ice diminishes and the volume of water increases, as is represented by the line marked " Volume of ice." The latent heat of ice is 144° Fahr., so that the process of melting goes on till 144 units of heat have been applied to the substance, and the whole is converted into water at 32° Fahr.

The standard temperature of water when it represents the standard specific heat of the substance —viz., 1—is 39° Fahr., so that at 32° it is somewhat less, and 182 heat units instead of 180 are required to raise it to the temperature of its boiling point (212°). At this point its volume has increased from the unit of volume at 39° Fahr. until it reaches 1·04315 at the boiling-point.

The next series of observations which call for attention occur when heat continues to be applied. and the process begins of boiling away the water. One 965th part of the pound of water passes off for each additional heat unit that is communicated, and in this way we get our original pound occupying the original unit of volume, 1 at 39° expanded into nearly 1,700 times its former bulk at atmospheric pressure. When the whole of the water has become steam, the vertical line representing the volume would, if drawn to scale, require to be extended 3,400 inches, or more than 286 feet long.

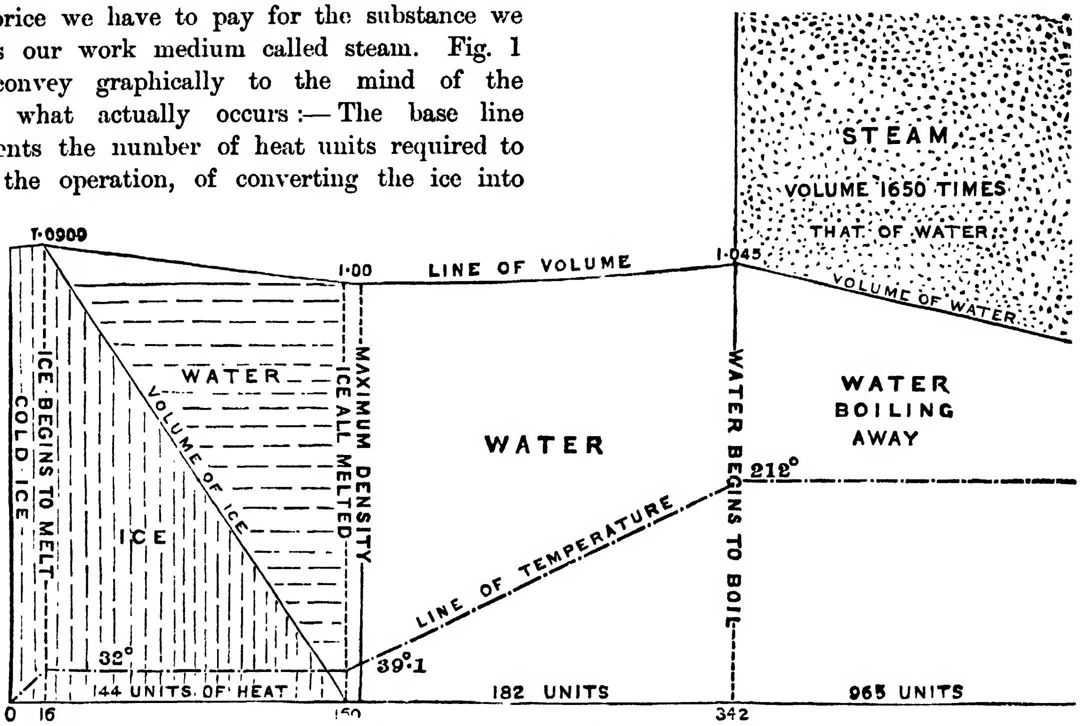


Fig. 1.—Diagram illustrating the Effects of Heat upon Ice and Water. (*From Clerk Maxwell's "Theory of Heat."*)

Having now obtained our steam, and paid for it in heat units as already described, we find ourselves very much in the same position as if we had started with an elastic fluid, like common air. Every heat unit that we now apply is no longer absorbed in converting the substance we are using from one state into another, but is directly available for storing up potential energy in the shape of an increase of pressure when the volume is kept constant, as in the case of a steam-boiler with a rigid form or figure. Now, for every unit of heat we add, we get an additional temperature

of 2·08° Fahr. at the atmospheric pressure. The volume of the steam also increases regularly in proportion to its absolute temperature; and, conversely, we get the corresponding increase of pressure if the volume is kept constant.

The position in which matters stand when "steam is up" in the boiler is complicated by the fact that under these circumstances we have two substances, viz., the water and the steam, that are affected in totally different ways by changes either in volume, pressure, or temperature. No change can take place with regard to any of these factors without leading to changes in the relative quantities of these two elements. The water remains water at a certain temperature only because there is a certain pressure exerted upon it by the pressure of steam. When this is increased, a certain quantity of steam is immediately converted into water; when it is decreased, a certain amount of water is converted into steam. So much heat is lost in consequence of the heat units absorbed in the operation, and if no further heat is added, a lowering of temperature ensues. This dual condition of liquids and gases involves a great many problems that are not directly connected with the question of heat-work; and so we will now go on to consider how we can best avail ourselves of the potential energy of steam after we have "raised" it.

Having started with 5,000 heat units we find that we have only 3,709 remaining to add to our low-pressure steam at the atmospheric pressure, and at the temperature of 212°. Now, in order to get our steam medium up to the pressure necessary for working a high-pressure engine, say at 74 lbs. on the square inch, we must heat it to a temperature of 307° F., and as each heat unit raises its temperature 2°.08, we will find that our store of heat will be further reduced. We have already allowed 182 units for raising the steam to the boiling point, and now we have to allow for the number of units required to raise the steam to a temperature of 307° at the rate of 2·08 degrees for each heat unit so added. In this manner 40 more heat units will be absorbed, and 1,331 will have been abstracted from our original supply of 5,000, in order to obtain our working medium of 1 lb. of water in the condition of steam at a pressure of 74 lbs. on the square inch. We will now suppose that this residue of heat—viz., 3,669 units—is similarly applied to other quantities of water, each weighing 1 lb., then as 1 lb. has absorbed 1,331 heat units, it follows that the whole of our original supply, viz., 5,000 heat units, would be capable of converting about 3·7 lbs. of water to steam at 74 lbs. pressure on the square inch.

It is here well to draw the attention of the reader to the important fact that whereas about 1,291 heat units are absorbed in converting ice into steam at atmospheric pressure, in which it cannot be made use of as a direct pressure medium at all, only 40 units are required for raising it from a potential zero, as regards doing work in a high pressure engine, to the very considerable amount of stored-up energy which is possessed by the steam which is obtained from 1 lb. of water raised to a pressure of five atmospheres. This shows what a vast saving of fuel would be attained if hot-air engines could be used instead of steam engines, as we would have the elastic fluid ready made, instead of having to pay for it as already described in the case of steam.

We will now go on to consider, first, what is the theoretical mechanical equivalent of the 5,000 heat units with which we started, and then see how much of this is available, in a high-class engine, as actual work.

The first part of the calculation, as the reader is already aware, is very simple: we have only to multiply the heat units by the foot pounds represented by each of them, viz., ·772. This will give us a total of 3,860,000 or the work of 117 standard horses exerted during one minute, or about 2 horse-power exerted during one hour.

We will first take that portion of our original store of energy represented by the 5,000 heat units which we expended in raising 1 lb. of water to steam at 60 lbs. pressure above the atmosphere, or 74·7 lbs. on the square inch. The temperature necessary for this condition of things is 307° Fahr. Now, if we take the most economical form of steam-engine provided with a condensing apparatus, by which we can obtain the greatest range of temperature, between the initial temperature of the steam and its temperature at the point when it ceases to fulfil any dynamic function, or, in other words, to do any work, we will find that it will still retain a temperature of 105° Fahr., so that the available range in our engine is the difference between these two measurements, or 202 degrees as representing the entire work done by the 1 lb. of water converted into high-pressure steam. The total heat we have paid for this, not allowing for any loss from the escape of our original supply up a chimney, or from radiation from the surfaces of the boiler steam-pipes and the working cylinders of the engine, is no less than the quantity already referred to,

viz., 1,331 heat units, so that in this way we obtain only a small fraction of the total quantity with which we originally started. If, however, we start from the theoretical zero, which we find in the air thermometer, we have a still larger margin of loss. Dr. C. W. Siemens, in a lecture which he delivered in Glasgow, in 1878, pointed out this loss of mechanical energy in a paragraph which makes the subject so clear that we cannot do better than quote it. He says :—" An engine capable of developing one horse power with two pounds of coal per hour is worked with a pressure of 60 lbs. above the atmosphere, or 74·7 pounds on the square inch, with a corresponding initial temperature of 307° Fahr., and a pressure in the conductor of 1 lb. on the square inch, corresponding to 105° Fahr. We find, by taking the ratio of the difference of these numbers to that of the greater, given in absolute degrees of temperature, that the efficiency of the steam is—

$$\frac{307 - 105}{307 + 461} = \frac{202}{768}$$

But we must also consider the loss of effect carried away by the heated products of combustion. The temperature of the fire may be taken at 2,500°, and that of the chimney at 500° Fahr., above the atmospheric temperature; and the ratio of the difference of these numbers to the greater gives—

$$\frac{2{,}500 - 500}{2{,}500} = \frac{4}{5}$$

as the efficiency of the furnace, which agrees with that of the best regulated furnaces worked with chimney draught. By the multiplication together of these ratios we obtain the combined theoretical efficiency of—

$$\frac{202}{768} \times \frac{4}{5} = \frac{808}{3{,}840} = \frac{2}{9} \text{ (approximately)}$$

of the steam and furnace worked upon the best known and approved principles.

"Thus it is shown that the best steam-engines now constructed are capable of realising $\frac{2}{9}$ths of the heat generated in the combustion of the fuel under the boiler, whilst the remaining $\frac{7}{9}$ths, form the margin for future improvement. A large margin, it must be owned, and one that can be dealt with only by increasing the range of temperature, the most perfect engine being one in which the temperature ranges from that produced in combustion, say 3,000° Fahr., to the minimum temperature producible in a condenser."

Dr. Siemens then goes on to show that the losses of heat which occur among the great industries, such as those embraced in the iron trade, is still greater than in the case of our supplies of motive power, but enough has been shown to prove how large a margin there is for improvement in the department of heat-work, and how severe a tax is at present being imposed upon our stores of heat-producing materials by the failure of science to provide a means of economising or saving this waste.

THE PARALLEL ROADS OF GLEN ROY.

By Professor T. G. Bonney, D.Sc., F.R.S., F.G.S.

In two or three of the glens on the southern side of that remarkable natural trench which severs the northern highlands of Scotland, and affords a passage to the Caledonian Canal, are some singular terraces, which, at Glen Roy, have received the name of the Parallel Roads.

Glen Roy is a valley, about ten miles long, in the heart of the mountain mass near the western end of the Great Glen. It descends into Glen Spean, rather to the east of Ben Nevis—the highest summit, as is well known, in Scotland. These "roads" have been familiar to geologists for many years, and the mode in which they have been formed has been a subject of controversy, which even now can hardly be regarded as settled. Of this, after a short account of the roads themselves, it is the purpose of the present paper to give a brief review.

As soon as Glen Roy is entered from its lower end, ordinary river terraces are noticed, which lie at a height of perhaps fifty or sixty feet above the level of the stream. These are carved out of a mass of coarse gravel and stratified sand, which fills the bed of the valley up to about the latter elevation. The stream, higher up, runs over slaty rock, but occasional masses of sand and gravel are seen in its vicinity, which, however, appear to be in more immediate connection with the openings of lateral glens.

The roads in Glen Roy are three in number, and all of them can be traced along the greater part of the glen (Fig. 1). The highest, however, ceases

at the opening of Glen Glaster, a tributary from the east, which enters Glen Roy some couple of miles above its opening into Glen Spean; the second road can only be followed round Glen Glaster; while the lowest extends to the very mouth of Glen Spean, and can be traced for a considerable distance along the flanks of that glen. They maintain an almost uniform elevation above the level of the sea—that of the highest varying from 1,144 to 1,155 feet; of the next, from 1,062 to 1,077 feet; and of the lowest, from 850 to 862 feet. They are shelves or terraces generally about forty to fifty feet in width, with a gentle outward slope towards the valley; overgrown with heather, and often strewn with blocks of rock, which have rolled down upon them from the rough hill-sides above. Their continuity is interrupted here and there by lateral ravines, but they extend up the larger tributary glens; they disappear also in one or two places where the flanks of the hill have become rocky and precipitous. Their aspect is most remarkable; the most striking view, which breaks suddenly on the traveller as he rounds a corner of a low hill-spur, being obtained from near the farm-house of Achnavaddy. Here, for the first time, all three of the roads come into sight, running along the sides of Dunearn and of the neighbouring hills. The slopes of these hills are unusually regular; this gives them a certain resemblance to a huge elongated mound cut into bastion-like blocks by small lateral glens. Here, then, the roads also are extraordinarily regular, resembling three railway embankments running along the flank of the hills. It is easy to understand how an uncritical age, which did not dream of the marvels of nature, but was credulous of the powers of magic, deemed them the work of men possessing superhuman powers, and asserted them to have been made for the convenience of Fion and his legendary heroes when engaged in hunting.

The main axis of Glen Roy extends up a lateral glen, called Glen Turit, round which the two higher roads may be traced, the lowest being soon cut out by the rise of its bed. But Upper Glen Roy bends round towards the east, and is prolonged for some three or four miles, the highest road being continued as far as the water-shed between it and the Spey, the other roads being soon cut out, for the bed of Upper Glen Roy, here composed of glaciated rock, rises rapidly. In Glen Gluoy, which communicates with Glen Turit by a flat col or depression, is a single well-marked road, about twenty feet above the highest in the latter glen; and a shelf, yet about twenty feet higher, may also be traced in Glen Kilfinnin, which lies some distance to the north of Glen Gluoy (Fig. 2). Terraces also—sometimes clearly, sometimes faintly, marked—may be seen in more than one part of the Spean valley, in addition to the more continuous one already mentioned. These are at various elevations above the sea, from 283 feet to 627 feet. The terraces rest upon the schistose rock of which the mountains are composed, and consist of detrital materials, chiefly angular fragments of rock, mingled with earth and occasional rolled pebbles in variable quantity. It is hardly possible to doubt that they are in some way or other, directly or indirectly, due to the former presence in the glens of sheets of water—are beach marks of some kind or other. But since the time when they were first noticed by scientific observers, they have been constantly the subject of controversy. The literature relating to them would fill a fair-sized volume, commencing in 1817 with the paper of Dr. Macculloch, and concluding with that of Professor Prestwich.* These controversies may be grouped under two heads—one, the minor, as to the precise mode in which the roads have been formed; the other, the more important, as to the physical cause to which they may be attributed. The former has been nearly, if not wholly, settled by Sir John Lubbock's interesting researches.† He shows that while, as above stated, there can be little doubt that the roads are, in some sense or other, indications of former water-levels, they cannot be regarded as ordinary beaches, whether of the sea or of a lake, their uniform outward slope—which varies from about one in eleven to occasionally as much as one in two—disproving anything like a heaping-up of materials by the action of waves. His explanation is as follows:—The rocky slope of the hill must, in process of time, have become covered with loose *débris*, the result of the ordinary subaërial disintegrating forces, and this would accumulate to a considerable thickness on all parts where the flanks of the valley were not too abrupt. If the valley then became occupied by water (whether an arm of the sea or a lake is for this purpose not material) as high as the level of the most elevated of the roads, the action of the waves, fretting against the *débris*, would

* "Philosophical Transactions," 1879, p. 663. References to other notices will be found in this memoir. A short note by Mr. J. R. Dakyns has also appeared in the "Geological Magazine" for 1879, written subsequently to the reading of Professor Prestwich's paper.

† "Quarterly Journal of the Geological Society," 1868, p. 83.

tend to excavate a notch in it,* but the incoherent materials not allowing this to be formed, there would be a constant slipping of *detritus* from above, which, being checked as it entered the water, would cover up the layer already below the surface of the fluid, and thus form a kind of broad sub-aqueous terrace, sloping gently outwards, and extending for some distance beyond the present exterior margin of the road. Then suppose some cause produced a more or less steady decline of the water, until the surface is again brought to rest for a time at about the level of the second road. The process of fretting, slipping, and sub-aqueous accumulation would be repeated, and by this means a portion removed from the exterior of the highest terrace, till the face of its outer slope corresponded with the angle of rest for loose *débris* in air. A second terrace would now be formed, as before, beneath the water-level; and then a further rise of the land or fall of the water would, in like manner, produce the third road. It can hardly be doubted that this explanation is, in the main, correct; and the exceptional character of the conditions required to allow of such accumulation of *detritus* would account for the rarity of these roads among the valleys of the Highlands.

Fig. 1.—The Parallel Roads of Glen Roy.

There remains, then, the more important question of the physical conditions under which these roads were formed—one upon which, at present, there is by no means a concord of opinion among competent judges; some regarding them as sea margins, others as lake margins; the advocates of the latter view, which may be designated as the more popular one, considering the lakes to be, in some way or other, the result of the former presence of glaciers in the Highlands. It is not easy in the brief space at our disposal to give a clear idea of the reasoning by which these two opposite theories are supported, but it will facilitate matters to enumerate certain facts connected with these roads, which are generally admitted. They are the following:—

1. That the Scottish Highlands were once occupied by large glaciers, perhaps almost buried beneath a sea of ice, much as is Greenland at the

* Mr. Dakyns mentions one or two instances where the rock beneath the road is notched—a new and important fact in the controversy.

present day, and that these, as the snow melted from the mountains and the ice retreated up the valleys, paused at intervals, and perhaps sometimes regained a portion of the territory which they had lost.

2. That there are many indications in Scotland that the sea once stood at least some two or three hundred feet above its present level, when beaches with grooves and terraces, not unlike those of Glen Roy, were formed.

3. That on the western side of Northern England and in Wales there is evidence (*a*) of a period when huge glaciers, or possibly an ice-sheet, occupied the country; (*b*) of a submergence beneath the sea, amounting in some places to not less, and probably more, than 1,500 feet; (*c*) of a return of the glaciers to some of the places from which they had disappeared.

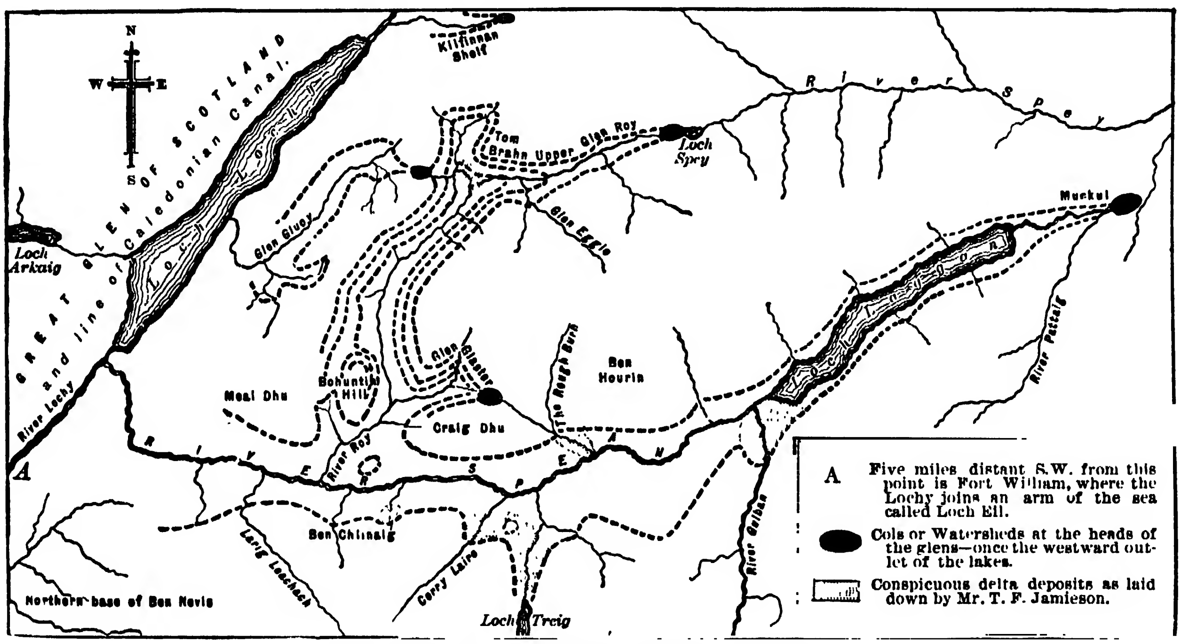


Fig. 2.—Map of Glen Roy and District. (*After Lyell.*)

4. That each of these roads corresponds very closely with the summit level of a col, or passage, leading from the head of a branch of Glen Roy into some adjacent system of valleys.

5. That no marine remains, or, indeed, any remains except a few fresh-water diatoms, have as yet been observed in the Glen Roy terraces.

We can now proceed to consider the explanations which have been offered of these singular Parallel Roads, and will notice, first, that which regards them as beaches formed, as mentioned above, by the action of the sea, when the land paused from time to time during a period of gradual, but not perfectly continuous, elevation. In favour of this view, it is urged that these terraces present many points of similarity with the admitted sea-beach terraces in other parts of Scotland, and with the numerous beaches associated with grooves on the face of sea-cliffs, to be seen in many places, as, for example, on the western coast of Norway. The sea, in the recesses of sheltered fjords, where it is but little affected by storms, and only rises and falls with the tides, would allow of terraces of unworn material; for in such positions, as we may see in Norway, its water would have but little abrasive influence on the rock fragments, and their angular character would be preserved. The coincidence with the "cols" is explained by the tendency to silt up which is exhibited by shallow straits; or, when the depth was a little greater, the action of tidal currents through the channels might augment the erosive influence of its waters, and this, even without having recourse to pauses in the slow elevation of the land, might explain the formation of roads nearly on the level of the cols—a coincidence which would be rendered yet more perfect by subsequent silting up. To those who lay great stress upon the absence of marine organisms, it is answered that in the low level and admittedly marine terraces both of Scotland and of Norway, marine shells are rare. This may be accounted for by the fact that these loose gravelly

deposits are unfavourable to the preservation of organisms; and further (as may be seen in Norway), fjords which pierce so deeply into the land are not very rich in molluscan life, the waters containing too little salt for ordinary marine molluscs, while they are too brackish to be tenanted by the molluscs of rivers. Still, it must be admitted that, while the presence of marine shells would be conclusive in favour of the marine theory, their absence, though not decisive against it, is a point on which its opponents may fairly lay considerable stress.

Passing, then, to the consideration of the other theory, almost all its supporters agree in attributing the Parallel Roads to the waters of a lake upheld by a glacier or glaciers,* while there is considerable diversity of view as to the exact mode in which its waters were maintained at the different levels. They point also to certain terraces on the margin of the Märjelen See, upheld by the Aletsch Glacier of Switzerland, as instances of the same kind, though on a very much smaller scale. The earliest view, that of Agassiz and Buckland, was that a glacier descending from one of the lateral glens of Ben Nevis had passed across Glen Spean, while a similar barrier was formed by another glacier issuing from the hollow now occupied by Loch Terig. To this it would be enough to reply that (as stated by Robert Chambers) the lowest of the three shelves extends far to the west of the second of these barriers, and that the theory neither explains the road in Glen Gluoy nor accounts for the blockage of the opening into Glen Glaster, through which, if it were left open, all the water must have been discharged down to the level of the second road in Glen Roy. We might further add that in the above localities no indication now remains of glaciers so enormous as this theory requires. They ought to have left their traces in the forms of huge lateral moraines; instead of this, they have vanished, and "left not a wrack behind." The theory was subsequently amended by closing the various cols by local glaciers, and supposing them to melt away one by one, and allow of the successive lowering of the great lake by an escape of the water over each col as the weakened barrier gave way. Glen Gluoy also was supposed to be blocked by a huge glacier which descended the Great Glen.

In this modified form the glacier lake margin theory was favourably regarded by the late Sir Charles Lyell; but apart from its highly artificial character, it appeared to me when I was on the ground that there was no valid evidence for the existence of these convenient "ice-corks." The physical structure of the region also strongly suggested that if once conditions prevailed which allowed glaciers adequate to retain such enormous masses of water to be formed on the flanks of Ben Nevis and in the valley of the Great Glen, then, not only would the heads of the lateral glens of Glen Roy be occupied by local glaciers, but the whole valley would be filled with ice, because the surrounding district appeared particularly suited to be a gathering-ground for ice. That it has so been filled I have no doubt; but this I believe, just as in Norway, was prior to the formation of the Roads.

Professor Prestwich, however, in his communication already mentioned, endeavours very ingeniously to overcome this difficulty, and to account for the almost inevitably simultaneous presence of both ice and water in the valley. He considers that during the period when the mountains of Scotland were occupied by very large glaciers, the low angle of descent and the peculiar arrangement of the valleys in this district would cause the glaciers to be crowded together in certain localities; and then the ice, thus jammed at the junction of conflicting streams, aided, perhaps, by moraine *débris*, would produce mounds or ridges, which in certain places might form barriers of some elevation across the openings of valleys. The rills descending from the surrounding hill-sides would thus be dammed back, and would form lakes resting upon the glaciers themselves, having, in general, ice instead of earth for their beds. Blockages of ice or morainic *débris*, would, in like way, prevent the escape of the water over the various cols; but these would ultimately yield more easily than the principal dams, and so allow of the escape of the water into an adjacent glen, and the consequent lowering of the lake. He considers, also, that the actual roads would be formed, not, as supposed by Sir John Lubbock, by the fretting action of the waves during periods of repose, but by the slipping down of the wet and incoherent materials during this epoch of rapid lowering of the water-level. This idea, however, seems to be disposed of by Mr. Dakyns' observation. He calls attention, in support of his main theory, to the existence of ice lakes of comparatively small size on various glaciers at the present day, and argues therefrom in favour of their attaining a much greater magnitude under the exceptional and peculiar conditions which he considers likely to

* We may pass by as wholly untenable a view which supposes the lakes to have been upheld by dams of morainic *débris* which have been subsequently removed.

have prevailed during the period of greatest glacial extension in Lochaber.

With regard to this view, ingenious as it is, we may fairly say that it is extremely doubtful whether ice blockages, to the extent required, would take place; whether they would not rise in dome-shaped masses rather than wave-like lines athwart the valley, or else the one glacier in part override the other; whether, if they thus swelled up, they would not become crevassed so as to be almost incapable of retaining water; and whether it is at all safe to argue from the existence of mere pools on glaciers at the present day to the possibility of large and comparatively deep lakes on a scale required. To form the Parallel Roads of Glen Roy, these sheets of water must have been ten, twelve, or even more, miles in length, and have occupied the whole breadth of the valley. We must, in fact, have had the whole glacier submerged—except, perhaps, some chance insular monticules of ice—for areas of many square miles. The conditions of the ice in Greenland cannot be so very diverse from that of Scotland during its period of greatest glaciation, but no indication of anything of the kind has been observed. Further, ought we not to expect confirmatory evidence in the form of a special accumulation of moraines on the hill-sides near these blockings? Certainly, among the Alpine glaciers, with which I am very familiar, I have seen nothing favourable, and many things rather adverse, to this last hypothesis.

The controversy, then, relating to the Lochaber roads may be thus summed up:—The difficulty of finding instances exactly parallel to them elsewhere is common to all the hypotheses, and may be fairly met by remembering that such roads as these could only be produced under very exceptional conditions. The advocates of the marine theory may urge the close resemblance between these and admitted sea-marks in other parts of Scotland and elsewhere, and point to the fact that a considerable submergence affected both Britain and Scandinavia subsequent to the period of greatest glaciation. They may explain, as above, the absence of marine organisms, and easily account for the presence of fresh water diatoms. The advocates of the glacial theory may decline to be satisfied with negative evidence in the latter case, and may devise various barriers for the retention of fresh water lakes. But, as it appears to me, these hypotheses involve yet greater difficulties than the other. So—unpopular as the opinion may be in these days, when a glacier or an ice-sheet is regarded by many eminent geologists as a *Deus ex machinâ*, capable of removing every difficulty and accomplishing every task, be it never so Herculean—I have always considered the marine, or, more correctly, the fjord theory the more probable, and looked upon these "parallel roads" as formed during the period of submergence which followed upon the first or greater extension of glaciers—that, in short, to which belong the shell-bearing drifts of Moel Tryfaen and the neighbourhood of Macclesfield.

STRUCTURELESS ANIMALS.

By Andrew Wilson, Ph.D., F.R.S.E., F.L.S., etc.

In one sense, the parallel between an animal and a machine of any kind may be admitted to be good and true. The application of the comparison is best seen when the higher animal is compared with the piece of mechanism. There are many analogies to be drawn, for example, between a watch and a complex animal body, such as that of a dog or of a man. Both watch and animal perform their functions by means of a complex arrangement of parts and organs, each destined for the work it executes; and both exhibit wear and tear as the results of living and working. The complex living being, like the watch, lives because it has organs to live with. If the harmonious relationship of its parts and organs be destroyed, life itself comes to an end, as surely as the work of a watch ceases when the spring is broken or the balance-wheel injured. There is thus a plain analogy between the living body and the machine. Of the higher plant, the same observations hold good; its intricate series of organs and tissues parallel the machinery of the watch. But the analogy and likeness do not run evenly and uninterruptedly throughout the whole of the animal and plant worlds. If we descend from, say, the quadrupeds to the lowest of the *Vertebrated* or "back-boned" animals, the fishes, the likeness still continues. The fish body is only a less complex machine than that of the quadruped, and it is, moreover, a structure which is built up on the

same type as the latter. Proceeding lower down in the animal series, we reach the "shell-fish" group. For example, a mussel, which has been already described, is just a degree less complex than the fish, and its frame is built up on a type or plan of very different nature from that seen in the vertebrate group. So also a lobster, exhibiting a third plan of structure, as we have seen, is likewise a simpler animal than the fish; and of the insect or spider, both of which agree with the lobster in general structure, the same remark holds good. Lower depths, however, still await our examination. As the merest tyro in natural history knows, the star-fish group, for instance, differs alike from fish, lobster, and mussel in the build of its body. It is less complicated than the lobster, and it is infinitely simpler in all its details than the fish. But despite this simplicity, the star-fish or sea-urchin yet exhibits a certain parallelism with the watch or machine. The machine with which the star-fish corresponds, must only be of simpler structure than that with which the fish is placed in comparison. As the machine works and performs its duties, so the star-fish body eats, digests, circulates its blood, and moves by means of special organs, developed in each case for the purposes just mentioned.

Star-fishes, however, present us with a type of by no means humble animal structure. There are infinitely lower deeps in existence than the star-fish group. Even the sea-anemone,* simple as we have discovered that animal's structure to be, is not ranked in the lowest grade. For the sea-anemone has tissues and organs and parts, which, if not quite so well-developed as those of even the star-fish, yet discharge well and truly the functions of its life. Only, we begin at the same time to note that in anemone-existence we see simple and single organs and tissues burdened with two or more of the functions which in higher animals are discharged each by a separate organ. For example, in the sea-anemone there is no heart. The function of circulating the blood in nutrient fluid, instead of being subserved by a heart as in star-fish, insect, mussel, and fish, devolves upon the *cilia*, or minute eyelashes lining the general body-cavity of the animal. As there is no heart in the anemone, so there are no blood-vessels; the tissues, as we saw in a previous paper, are literally bathed in the fluid which is destined to nourish them. If, therefore, the sea-anemone is a kind of living machine—and there is no reason to cavil, scientifically or otherwise, at the term—it is a simpler machine than its neighbour animals already mentioned. Its mechanism, so to speak, tends to become simpler, in the manner which would be represented by the works of a watch, which, instead of possessing the multifarious wheels common to these machines at large, performed at once simpler duties in timekeeping, and exhibited therefore a less complex mechanism.

* "Science for All," Vol. IV., p. 151.

But descending to still lower grades of life than those in which the anemones and their neighbours exist, we light upon animals of still more striking simplicity of form and function. Suppose a watch to possess none of the internal belongings of its race: its functions as a timekeeper would be utterly annihilated. Its characteristic structure as a machine, would be lost likewise, and it would no longer be entitled to be ranked amongst pieces of mechanism of any kind. The parallel between a "worksless" watch and certain lowest grades of animal life is, after all, as strict as is the analogy between the perfect watch and the complex higher animal. But whilst the "worksless" watch is a contradiction in terms, the "worksless" animal is a reality of life. All the details of structure which distinguish the higher animal and make the complex being what it is, may be absent, and yet life in its lower deeps may perform its functions none the less perfectly—the absence of organs notwithstanding. Whilst the "worksless" watch is an anomaly of art, the structureless animal is a reality of nature. And to structureless animals we might add structureless plants—for the plant world in its lower confines, equally with the animal creation, appears to live and to have its being without the means and mechanism so plainly apparent in the familiar plants of every-day life.

A few examples of structureless animals will serve to illustrate and to apply the foregoing remarks on the relative degrees and differences which mark the constitution of the units of the living series. Existing in the waters of the sea, and in fresh waters as well, we find a series of microscopic jelly-like specks, many of which are not longer than the one-eight-hundredth part of an inch. Placed beneath the object-glass of the microscope, these forms appear to our eye each as a minute mass of jelly, which may either be colourless or may be tinted of an orange hue. The naturalist would inform us that these are masses of the substance known as *protoplasm*, or *sarcode*, of which already, at different times, we have had something to say That they are alive we could not for a moment

doubt, for two reasons: firstly, we see exemplified in each the power of independent movement; and secondly, we observe each living speck to take matter from the outer world, and by receiving such matter within its frame, to feed itself. Thus, like the highest animal, it grows and obtains the energy requisite for the performance of the movements of life.

Let us watch one of these specks—such as are called by the naturalist *Protamœba*, or *Protomyxa*. The first point in the history of such an organism which arrests our attention is its literally marvellous power of incessant change and alteration of shape. *Protamœba* (Fig. 1), for instance, is continually

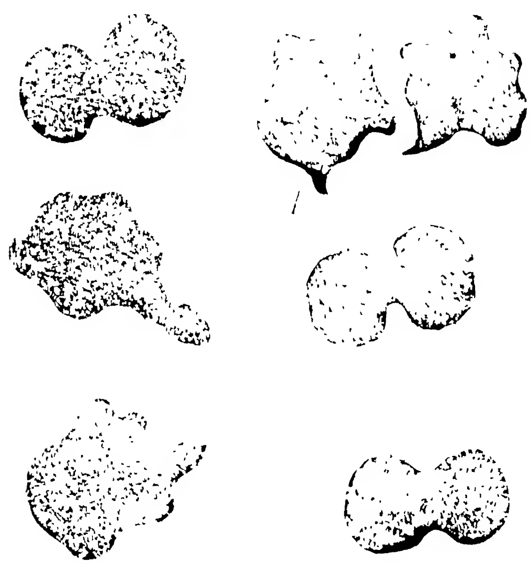


Fig. 1.—*Protamœba primitiva* undergoing Development by Fission.

shooting the margin of its body into blunt-shaped projections of its substance; and if we watch it carefully, we see that it moves by throwing forward such projections, and by absorbing the body gradually into them. It may be either described as, in reality, having no definite shape at all, or as possessing every shape and form conceivable. The name *Amœba* itself means "change;"* and although this term is applied, as we may presently note, to a distinct relative of the *Protamœba*, the latter exhibits the family character of the group in its power of incessant change of shape and form. More careful observation shows that the *Protamœba* has no vestiges of the structure of even the sea-anemone. You may almost see through and through the jelly-body of the animalcule. Within its limits, there is no trace of a mouth or other feeding apparatus. No heart or circulatory apparatus is to be seen, no nervous system, even in its most rudimentary phase, is discernible. It wants, in fact, every structure by the possession of which we recognise the animal frame at large. In a word, it is the parallel of the "worksless" watch. We see before us an animal form, existing and living, without any apparent organs to carry on the functions of life. At the very most, we can only say that the outer layer of the jelly-body is firmer than the inner substance; and that is the outer layer (or *ectosarc*, as it is called) which is the active seat of the movements already described. It is from this outer layer, in other words, that the finger-like processes of the body (or *pseudopodia*) are protruded (Fig. 1, *p*). When the animalcule thus projects its body-substance we can see that the matter of its body is of semi-fluid character; for the granules which exist in the more central protoplasm of its body then run into the projecting portions. These granules appear to exhibit an incessant motion, and to flow and reflow like the currents we may see in the cells of many plants, and which have before been described in these pages.*

Furthermore, however, we may discover another use for this power of projecting the protoplasm of the body outwards from itself. By aid of its "pseudopodia" the animalcule is enabled to obtain its food. Like every other living being, it requires to receive matter from the outer world, and to convert this matter (or "food") into its own substance before it can live and move. In this respect it is on a perfect footing of equality with man himself. When the soft margin of its body, moreover, comes in contact with any solid particle, it shoots out its body-substance into processes which encompass the particle, and by so surrounding it finally engulf it within the body-substance. From this we learn two facts of importance: firstly, that it is evident the protoplasm of the body is sensitive to outward impressions; and secondly, that in the absence of a mouth, food is ingested by any part of the body's surface. But for this sensitiveness the animalcule could not exist. It might as well be an inorganic thing, were it unable to act upon the stimulus which the contact of food-particles supplies. And we thus discover, even in these lowest forms of life, the faint beginnings of the same power of receiving and acting upon impressions which characterises the

* "Movements of Living Beings:" "Science for All," Vol. IV., p. 108.

highest members of the living world. The nervous system is necessary for the performance of this generalised work of receiving impressions. All we can say concerning the manner in which the function in question is performed is, that wherever we meet with living protoplasm, it seems to possess this property of sensitiveness as one of its primary and unfailing characteristics. We never meet with this substance in a living animal or plant without observing sensitiveness as one of its chief details.

Food received into the body of the *Protamœba* is unquestionably "digested:" that is, it is converted into new protoplasm, and thus repairs the waste of tissue to which the animalcule, in common with every other living being, is continually being subjected. How "digestion" and "assimilation" are exactly accomplished in lower life, we do not perfectly comprehend. But it appears most certain that the particle of food is affected in some way by the protoplasm which surrounds it; its nutrient parts are in this way appropriated, and those portions which are indigestible are simply rejected by that part of the body-margin which is nearest the food. In respect of the development of new *Protamœbæ*, there seems (so far as has been observed) to be only one form of the reproductive process represented in its history. New animalcules, which are to replace those that are continually dying off, are produced by the simple *fission*, or division, of the body of an existing *Protamœba* (Fig. 1). None of the more complex developments, seen in the sea-anemones, or even in other animalcules of lowly grade, have been witnessed in this simple form of life thus introduced to our notice.

Forms allied to *Protamœba*, and called *Protogenes*, differ from the former, in that the processes they protrude from their body-margin are more delicate than those of *Protamœba*; and these pseudopodia in the *Protogenes* further interlace and intertwine in a manner unknown in the beings we have just described. Then, also, we note the interesting fact that certain of these lower forms, strictly comparable each to a *Protamœba*, seem to possess the power of fusing their jelly-like bodies together, so as to form a mass or "colony" of similar organisms. Such a colony receives the name of a *plasmodium*, and the organism named *Myxodictyum* (Fig. 2) is an example of such an associated series of beings. Further modifications are witnessed in the life of these beings, although in all, the same structureless body-substance is to be seen. Thus one form, known as *Vampyrella*, lives upon certain of those beautiful lower flint-covered microscopic plants known as diatoms. Vampyrella possesses interlacing projections, or "pseudopodia;" and by means of these projections, which it inserts between the flinty coverings of the diatoms, it sucks up or absorbs the protoplasm of these lower plants, and lives upon the matter thus obtained. If, as seems probable, Vampyrella is an animal form, its act of living upon plant-protoplasm is strictly parallel, after all, with that of a cow eating grass. Vampyrella has further been noticed to creep from diatom to diatom, through the whole series growing in a cluster, in its search after nutriment, absorbing the con-

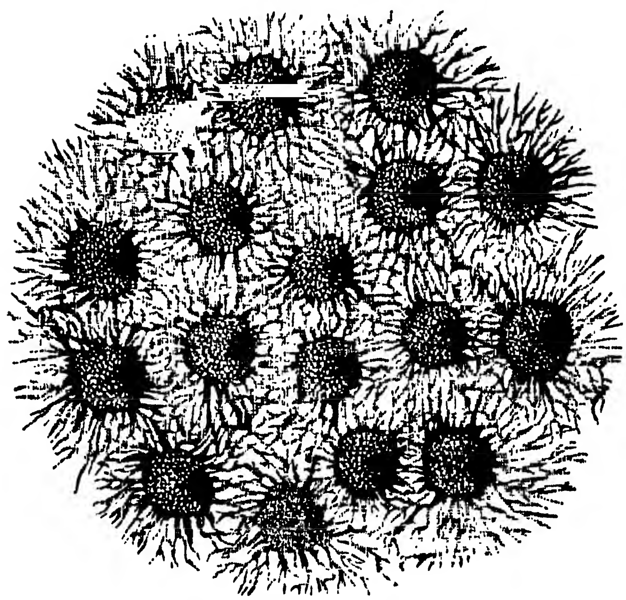


Fig. 2.—Myxodictyum sociale.

tained protoplasm; and after having destroyed the diatom-colony, it has been observed to locate itself in the place of the last of its victims. Then, drawing in its projecting filaments, it seems to become spherical in form. Next, there grows around its soft body a structureless envelope, and its protoplasm divides into four masses of equal size. Each mass into which the Vampyrella body has thus become divided seems to escape from the parental envelope, and then assumes all the habits of the being from which it was derived. Here we see a little complication of the simple development seen in Protamœba. A parent-body in Vampyrella first becomes quiescent, then divides into four equal parts, each of which is, in fact, a new animalcule. It is also interesting to observe that the development of the highest animals begins at least in an analogous fashion by the division of the parent-germ, or egg.

If these remarks be taken as a brief description

of the lowest forms (*Monera*) of animal life known to biologists, we may next glance at other and allied beings, which, whilst showing a little advance upon these first organisms, yet present us with a simplicity far below that of all ordinary animals. The *Amœba* itself, one of the commonest animalcules found in our pools and stagnant waters and infusions, presents us, as has already been shown, with all the characters seen in one of the *white corpuscles* of our blood.* It is curious to think that rolling along through our blood-vessels, and forming normal parts of the life-giving stream, are millions of small particles of protoplasm, exactly comparable to an Amœba. Nay, more; for when drawn from the body, and kept in a duly heated microscope slide, these white blood-globules are seen to protrude their substance in exactly similar fashion to the Amœba and Protamœba themselves. Our white blood-corpuscles, in a word, are simply protoplasmic cells, which have acquired an independent existence in our tissues.

The *Amœba* does not materially differ from the Protamœba, except in one or two particulars. Thus, firstly, the Amœba possesses a solid particle, or *nucleus*, which the Protamœba wants. Then, secondly, we can detect one or two or more clear spaces, called *contractile vesicles*, within the Amœba's body, and these are absent in Protamœba. These

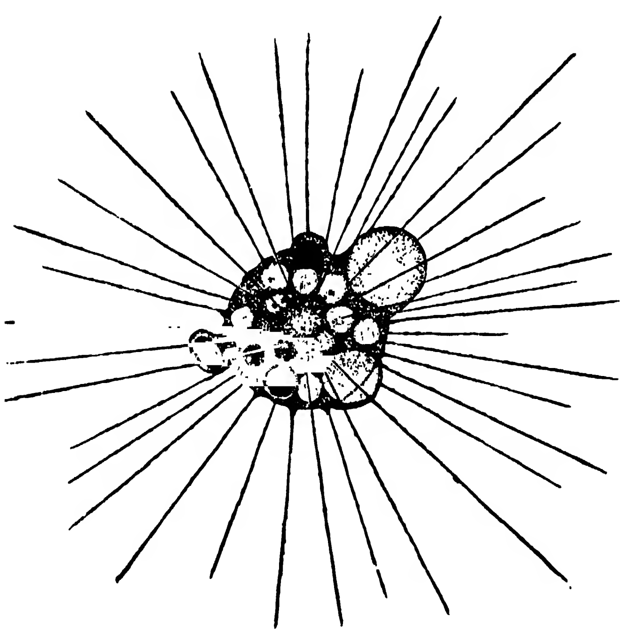


Fig. 3.—Actinophrys sol.

vesicles derive their name from the fact that they are seen to contract and expand with tolerable regularity. Their movements have suggested to the minds of naturalists that possibly they may represent a rudimentary form of heart, and as such, may

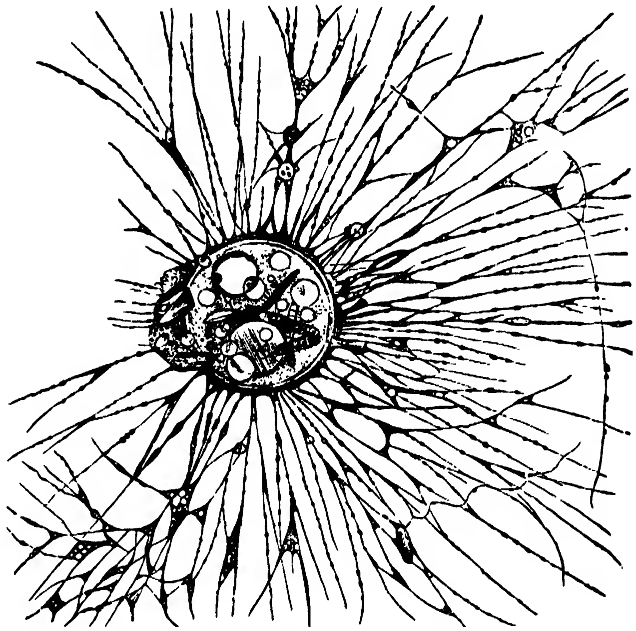


Fig. 4.—*Gromia terricola*, showing interlacing "pseudopodia."

distribute the fluid they contain (most probably water) through the protoplasm of the body. It is a very interesting fact to note that the white blood-globules of certain members of the frog's class (*Amphibia*) seem to resemble Amœba, not merely in the possession of a nucleus and in emitting processes of their substance, but likewise in exhibiting each a contractile vesicle as well.

From the *Amœba* and its neighbours, a near transition leads us to certain interesting animalcules, which, whilst of equally simple structure, yet develop around their bodies "shells" or "tests" of beautiful and often complex structure. Certain near relations of the Amœba possess the power of giving off the "pseudopodia" from one region or part of the body only, instead of equally from any part of its surface; the rest of the body in such a case remaining immobile and passive. Such a state of matters is seen in the animalcule which has received the name of *Lieberkühnia* (Fig. 5). Here, the body is to be compared simply to an Amœba which has acquired a stolidity of body save at one part, and from this latter part are protruded the processes whereby food is seized and locomotion effected. A step onwards takes us to another animalcule, called *Gromia* (Fig. 4). Here, as in *Lieberkühnia*, there exists the power of emitting projections from one region of the body only; but,

* "Science for All," Vol. IV., p. 110.

in addition, the immobile part of *Gromia* has become invested by a membranous layer of somewhat dense character, and which, in all essential respects, serves as a kind of protecting "shell."

From *Gromia* we pass by easy transitions to the animalcules already described under the name of *Foraminifera*, and which may be popularly called "chalk animalcules," seeing that in the present, as in the past, the massing together of their living shells constitutes the "chalk" of the geologist (p. 65).

Allied to the Foraminifera are the *Radiolarians* (p. 70, Fig. 4). These latter differ from the former chiefly in the fact that their "shells" are formed

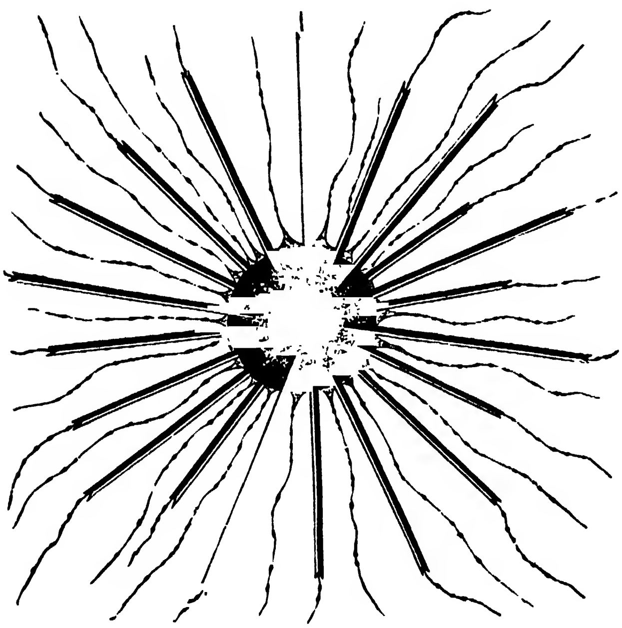


Fig. 5.—Lieberkühnia.

of flint instead of lime. The curious "Sun-animalcule" (*Actinophrys*, Fig. 3) of our pools seems to lead from the Amœba-like animalcules to the Radiolaria, just as *Gromia* and *Lieberkühnia* link the Amœba-stage with the Foraminifera. In the "Sun-animalcule," the centre of the protoplasmic body contains a number of *nuclei*, and in the Radiolaria themselves the central part of the animalcules contains a capsule or nuclei, or crystalline bodies; whilst in the outside layer of the body there is developed either flinty spicules or a "shell," which may exhibit the most elegant mathematical symmetry and beauty of form. Indeed, nothing in nature or in art can well equal the marvellous beauty and regularity observable in many of the shells of these lowly creatures. Existing, like the Foraminifera, mostly in the sea, their flinty shells sink in time to the bottom, and mingle with the chalk *débris* into which the foraminiferous shells ultimately dissolve. It is at least a fact to be borne in mind, that whilst one particle of protoplasm selects lime as its shell-substance, another selects flint, and both particles, like the Amœba, are destitute of all the structures seen in higher animals. They correspond to the "worksless" watches, which, strangely enough, "go" with the utmost perfection in their own ways and methods of life.

A passing reference to the *Gregarina* (Fig. 6) may complete our list of structureless animals. *Gregarina* is a minute speck of protoplasm, living as a parasite in the digestive system of worms, beetles, lobsters, and other animals. The body has simply a *nucleus*, but there are no contractile vesicles. It may exhibit slow contractions of its substance, but otherwise leads a truly vegetative life. Existing in the very "kitchen" of its host, where it both "lodges" and "boards" as a free guest, the Gregarina is bathed amidst the nourishment its host is elaborating for its own use. Nothing simpler than Gregarina's existence can well be conceived. To the structureless body of an Amœba, it unites a want or absence of movement, and possesses no power of emitting pseudopodia, such as constitutes a chief characteristic of the other forms we have examined.

Summing up our researches into the lower forms of animal life, we have discovered, firstly, that the lowest animals, and the lowest plants as well, exist as mere specks of protoplasm, destitute of all structure. Secondly, we have noted that this protoplasm may exhibit varying degrees of simplicity. It is thus, if anything, of simpler character in a Protamœba than in an Amœba. Thirdly, we have seen that the parallelism between animals and machines cannot be pushed to the verge of lower existence. Whilst a dog or a man are comparable to watches, in that each has complex vital machinery to live with, the lowest forms of life live perfectly in their own way, but without possessing even the bare rudiments of organs or tissues. Life is thus capable of being perfectly, even if simply, carried on in the entire absence of *organisation*—that is, the possession of definite structures and organs. Life precedes and perfects the organisation we see in higher life; organisation does not cause life. A watch *is* a watch because it has works; the "worksless" watch, as we have seen, is an anomaly and a paradox. But the unorganised animal or plant is a reality of nature,

and as such, destroys the parallelism between the mechanical and living conceptions of the organic universe.

It is necessary to add a concluding word concerning the peculiar substance named *protoplasm*, or *sarcode*, and which in itself, as we have seen, is perfectly competent to discharge all the functions of nourishment and reproduction which belong to lower life. Very various theories have from time to time been entertained concerning the relations of this protoplasm to the life it exhibits. With these speculations, which really concern the nature of life, we have nothing whatever to do. What is an accepted and proved fact is that life is not known to exist except as exhibited by and through protoplasm. It is probable that all forms of protoplasm may not be chemically similar. As analysed, it is found to be a form of *albumen*, and to consist of carbon, hydrogen, oxygen, and nitrogen, with traces of phosphorus and sulphur. It is certain, however, that all living beings have not only their beginning in protoplasm, but that they likewise carry on the work of life by means of this substance. The egg and germ of every animal and plant is a speck of this substance; the cells of which the adult animal or plant is composed, possess this matter as their essential constituent. Brain-cells, liver-cells, bone-cells, muscle-cells, blood-cells, and all other cells of the highest forms of animal life, are essentially protoplasmic in their nature. Without a doubt, the brain-cell is the seat of thought, as the liver-cell is the manufactory of bile, or as the bone-cell is the focus around which new bone is formed. Universally present, then, whatever "life" may be conceived to be, protoplasm is its one "physical basis," without which life is to us unknown. More than this is not at present certain: farther than this declaration the exact dicta of science cannot as yet pass. Whether the future labours of biology and other sciences will show us the essential nature of life—or whether that secret will remain for ever entombed among the arcana of knowledge—who can tell?

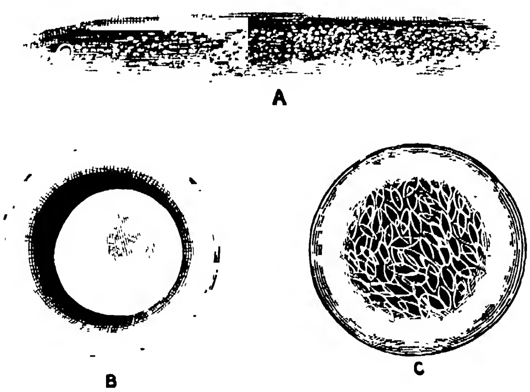


Fig. 6.—Development of Gregarinida. (*Highly magnified.*)

A, Gregarine of the Earth-worm in its Ordinary Aspect; B, in Encysted Condition; C, showing division of Contents into Pseudonavicellæ. (*After Stein and Lieberkuhn.*)

A PIECE OF SULPHUR.

By F. W. Rudler, F.G.S.,

Curator of the Museum of Practical Geology, London.

Few persons in this country, unless they happen to be specially interested in mineralogy, ever have an opportunity of seeing a piece of sulphur in its raw or native state. They may be familiar enough with the solid sticks of brimstone, or with the yellow powder known as "flowers of sulphur," or even with the still finer material sold by the druggist as "milk of sulphur;" but all these forms of the substance have been subjected to artificial treatment, and are far from representing the sulphur as it occurs in nature. There is no place in this country where a man can dig into the ground and find sulphur; but in volcanic districts—even where the subterranean forces have been well-nigh spent—it is not uncommon to find abundance of sulphur around the margin of the volcanic vents. Such is the case, for instance, at the famous Solfatara, near Naples, where the surrounding soil becomes impregnated with sulphur in sufficient quantity to be well worth the trouble of working. The very name *solfatara*, which is now applied to any fissure whence volcanic vapours issue, is evidently connected with the Italian word *solfo*, or sulphur. A solfatara is a kind of stifled or half-dead volcano, and wherever volcanic action is or has been rife, it is likely enough that sulphur may be found.

When the Spaniards under Cortez ran short of gunpowder during the conquest of Mexico, they naturally turned their eyes to the smoking cone of

Popocatepetl, hoping to find there the sulphur which they so much needed. Nor were they disappointed. An exploring expedition was despatched, and when the adventurers, after a toilsome journey, reached the crater at a height of more than seventeen thousand feet above the sea-level, there, surely enough, was the object of their quest—the yellow sulphur lining the throat of the burning mountain!

Nothing is more natural than to suppose that the sulphur in a volcano has been brought up from below as sulphur-vapour, and simply condensed upon the cooler rocks with which the vapour happened to come in contact. There is good reason, however, to believe that the immediate origin of the sulphur is not quite so simple a matter as this. Among the gases and vapours belched forth from a volcanic vent, there may generally be found two compounds containing sulphur. One of these is that gas which is smelt whenever a common lucifer match is struck—a gas which is always associated with the odour of burning brimstone, and which is known to chemists as *sulphurous anhydride*, or, when combined with water, as *sulphurous acid*. This is a compound of sulphur and oxygen. The other volcanic exhalation containing sulphur is the gas termed *sulphuretted hydrogen*—a combustible gas, of uninviting odour, generally compared to the smell of rotten eggs or of putrid cabbage-water. This gas is a compound of sulphur and hydrogen. Now, when these two gases are brought into contact, as they certainly are in the out-going stream of volcanic vapours, they decompose each other, the hydrogen of the one uniting with the oxygen of the other to produce water, while the sulphur of both is set free in a solid form. It is a telling lecture-experiment to take these two gaseous bodies—perfectly colourless and invisible—and to show how they produce by their reaction a solid deposit of yellow sulphur! It is probable that a chemical action of this kind has given birth to much of the sulphur found in the neighbourhood of volcanoes.

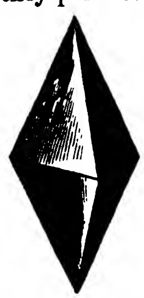


Fig. 1.—Octahedral Crystal of Native Sulphur.

Although native sulphur frequently occurs as a yellowish crust spreading itself over the surface of volcanic rocks, without having any particular shape of its own, it occasionally happens that the sulphur asserts its power of crystallisation, and appears in very definite and beautiful forms. Fig. 1 represents a simple sulphur-crystal—an octahedron bounded by eight unequal-sided, or scalene, triangles—while Fig. 2 depicts an unusually fine crystal, heavily charged with faces. All the faces of such crystals bear definite relations to a set of axes which the crystallographer, by the scientific use of his imagination, may picture within the crystal. Such a group of axes is represented in Fig. 3; and as these three lines are of three different lengths, the system to which the sulphur crystals belong is often called the *trimetric system.*

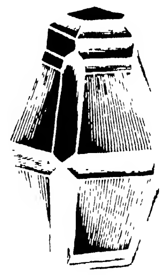


Fig. 2.—Complex Crystal of Native Sulphur.

Is it possible to imitate nature, and to produce similar crystals of sulphur in the laboratory? This question may be answered if we can succeed in dissolving the sulphur. Solution and slow solidification form one of the readiest means of inducing crystallisation; for the particles or molecules of the body have thus free play to arrange themselves in obedience to what we may call their crystal-forming instinct. Now sulphur is insoluble in water: a piece of brimstone placed in the vessel of water from which a dog drinks may remain there for months without being dissolved. But though water is unfit for our purpose, the chemist is acquainted with a certain liquid, called bisulphide of carbon, which dissolves sulphur with great facility. Let a small quantity of powdered sulphur be shaken up with some bisulphide of carbon, and the sulphur disappears as readily as a piece of sugar disappears in a cup of tea. If the solution which is thus obtained be allowed to evaporate with extreme slowness, it gives rise to crystals belonging to the trimetric system, and therefore bearing considerable resemblance to those of native sulphur. Similar crystals may be obtained from a solution of sulphur in turpentine, or in benzene, or in petroleum.

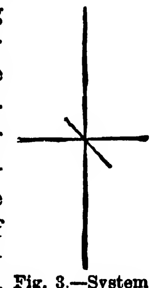


Fig. 3.—System of Trimetric Axes.

There is, however, another way in which chemists are in the habit of coaxing a substance to crystallise. If the solid can be melted or fused, its particles are loosened from their rigid connection, and when the molten mass slowly solidifies, they can group themselves in such fashion as the laws of crystallographic symmetry may demand. In this way some curious crystals of sulphur may be obtained. Melt a pound or two of brimstone in a crucible, and allow it to cool until a crust forms over its surface; next, pierce this crust, and let the bulk of the

sulphur run out through the aperture; it will then be found that the sulphur which clings to the inside of the crucible shoots out in delicate needle-like crystals, so that on breaking away the crust the interior of the vessel displays a network of interlacing yellow fibres, like those represented in Fig. 4. Each of these sulphur needles is a prismatic crystal, entirely different from a crystal of native sulphur, and not related to the trimetric system. Its form requires that one of its three axes should be inclined to the plane in which the others lie, as in Fig. 5; and hence the system in which the molten sulphur crystallises is called the *monoclinic system.*

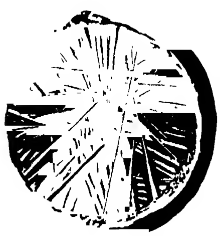


Fig. 4.—Sulphur Crystallised from Fusion.

When describing a piece of black-lead, it was explained that if a body can crystallise in two distinct systems it is said to be *dimorphic.* Sulphur is accordingly a dimorphic body: the natural crystals, and those produced from solutions at low temperatures are trimetric; while those obtained by fusion are monoclinic. But the monoclinic modification is not stable. In the course of four-and-twenty hours a transparent crystal of monoclinic sulphur will spontaneously become opaque, and, without changing its external form, will be converted into a multitude of minute crystals of trimetric type. The same change may be rapidly induced by scratching the crystal; opaque spots first appear at the point which has been touched, and the change then gradually spreads throughout the mass. Conversely, a transparent crystal of octahedral sulphur, if kept for some time heated nearly to its melting point, will assume an opaque appearance, and will break up into a great number of prismatic crystals. It is thus seen that a piece of sulphur is remarkable for the molecular changes which it is capable of undergoing, a crystal passing with ease from one dimorphous condition to the other.

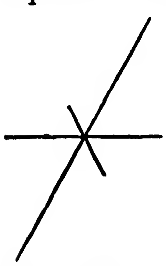


Fig. 5.—System of Monoclinic Axes.

But in addition to these two crystalline modifications of sulphur, there is another form of the substance which the chemist obtains by rapidly cooling fused sulphur, and which is utterly destitute of all crystalline character. It is curious to watch the strange changes which sulphur undergoes when melted. First, it forms a thin, clear, amber-tinted liquid. Then, as the heat is increased, this liquid becomes thicker in consistency and darker in colour, until at length it looks like so much treacle, and the vessel may even be inverted without any outflow of the viscid sulphur. But, curiously enough, if the temperature be still further raised, the sulphur again becomes liquid, though not quite so thin as when first fused. At a yet higher temperature, the sulphur passes into an orange-coloured vapour.

Now, if the molten sulphur, when in a liquid condition, be poured into cold water, it at once solidifies; but instead of forming a hard brittle solid, it is so soft and plastic that it may be readily moulded by the fingers, and even drawn out into long, tough, elastic threads, like a piece of soft india-rubber. This *plastic sulphur,* however, is unstable. In a short time it loses its plasticity, and reverts to its ordinary hard and brittle state—a change which is attended with the evolution of considerable heat. While in its elastic condition, it is, in every respect, unlike ordinary sulphur. For example, ordinary sulphur is freely soluble in bisulphide of carbon, but the plastic sulphur is insoluble. Again, the specific gravity of plastic sulphur is only 1·95, while that of the monoclinic, or prismatic, variety is 1·98, and that of the trimetric or octahedral form reaches as high as 2·07. A piece of sulphur is therefore a body of singular interest to the chemist and the physicist: it offers, in fact, one of the best illustrations of *allotropism,** or that power of molecular change whereby one and the same body can assume a variety of forms, each with a distinct set of physical properties.

In addition to the three allotropic modifications previously described, there is a fourth form of sulphur which needs a passing notice. Under the name of *milk of sulphur,* the druggist sells a greenish-yellow powder, which he obtains by adding an acid to a solution containing sulphur, usually a solution of a particular compound of sulphur and calcium. The sulphide is thus decomposed, and the solution becomes milky or cloudy in consequence of the separation of free sulphur, which gradually falls to the bottom in a very finely-divided condition. Anything thus thrown down from a solution is called, in chemical language, a *precipitate;* and hence milk of sulphur is sometimes termed *precipitated sulphur.*

Under the microscope, the milk of sulphur is seen to consist of granules utterly destitute of

* "A Piece of Black lead:" "Science for All," Vol. V., p. 17

crystalline structure, whence it is recognised as an *amorphous* variety. This variety is soluble in the ordinary solvents for sulphur; but the chemist is acquainted with another amorphous modification which is insoluble. The bare mention of such facts is sufficient to indicate the curiously fickle character of sulphur. This single species of elementary matter is, in fact, capable of assuming a plurality of forms, which is perhaps greater than that of any other Protean element.

It is worth noting that precipitated sulphur may be obtained by the spontaneous decomposition of a solution of sulphuretted hydrogen—a decomposition which has probably given rise to some of the native deposits of sulphur. Sulphuretted hydrogen is freely soluble in water, forming at first a clear solution; but if this solution be exposed to the air it is apt to turn milky, in consequence of the separation of finely-divided sulphur. The oxygen of the air combines with the hydrogen of the sulphur compound, with production of water, while the sulphur is set free and precipitated. Natural waters frequently contain sulphuretted hydrogen, acquiring thereby a foul odour, but also acquiring medicinal virtues. Such sulphuretted springs occur abundantly at Aix-la-Chapelle, and to a less extent in this country, as at Harrogate, in Yorkshire. These *hepatic* waters readily decompose, and yield sulphur. Hundreds of pounds of sulphur, produced in this way, have sometimes been collected from the walls of the springs at Aix-la-Chapelle. There can be no doubt that a similar decomposition has yielded much of the native sulphur—especially that which is found in sedimentary deposits, far away from any volcano. At Teruel, in Spain, there is a curious deposit, in which large numbers of fresh-water shells are preserved or fossilised in sulphur. In such cases the sulphur appears to have been deposited from sulphureous springs which poured their waters into a lake in which sedimentary deposits were in course of formation—the deposits thus becoming impregnated with sulphur.

An excellent illustration of the production of sulphur at the present day may be seen at the Sulphur Bank, near Clear Lake, in California, where the vapours and gases issuing from the various fissures deposit not only free sulphur but several of its metallic compounds. Again, many of the hot springs or geysers in the Yellowstone National Park exhibit a deposit of sulphur around the margin of their basins.

A large portion of the sulphur of commerce is obtained from stratified deposits of Tertiary age, consisting mainly of clays and marls, limestone and gypsum. The sulphur occurs either in veins or in concretions, or still more frequently in a finely-divided form impregnating the rock, and thus forming a "sulphur ore." Such sulphur-bearing rocks have been worked for ages in Sicily—especially in the neighbourhood of Girgenti—and also near Cesena, in Romagna. These two districts still supply the world with most of its sulphur. Its mode of occurrence will be understood by the section represented in Fig. 6, which shows the succession of beds at San Marino.

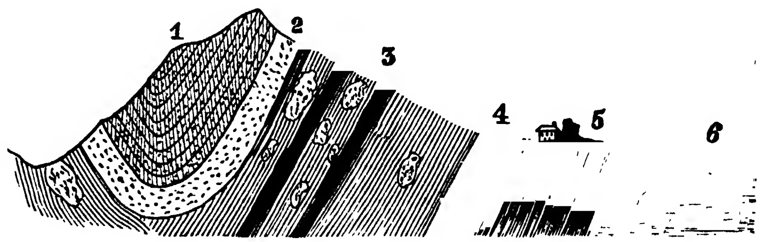


Fig. 6.—Section of Sulphur-bearing Rocks at San Marino, Italy. 1, Clays; 2, Sandstone; 3, Schists, with Gypsum; 4, Gypsum, with Sulphur; 5, Clays and Marls; 6, Pliocene Marls.

Sulphur-mining in Sicily is carried on in most primitive fashion, and even in Romagna the workings, though better, are still but crude. After the rock has been broken up, the sulphur is extracted by a simple process of *liquation*—that is to say, the rock is exposed to heat until the fusible sulphur sweats out. This liquation is principally carried on in large kilns, termed by the Italians *calcaroni.* Fig. 7 represents such a kiln. Here it is seen that a large heap of the sulphur-rock has been placed within a circular wall of masonry and set on fire; the melted sulphur then trickles to the bottom of the heap, and flows down the inclined floor towards the door, or opening, called a *morte*, whence it ultimately escapes.

Obtained in this way the sulphur is still impure, and needs to be refined before coming into the market. For this purpose the crude sulphur is generally heated in an iron retort, which is placed in communication with a large brick chamber. The sulphur in the retort, after having been melted, volatilises; and the vapour passing into the chamber condenses upon the cold walls as a fine powder. This powder is the well-known *flowers of sulphur.*

The transformation of a substance from the state

of vapour to that of a solid, without passing through the intermediate condition of liquidity, is termed *sublimation*, and it is therefore common to speak of the flowers as *sublimed sulphur.* If required absolutely pure, the powder should be washed to free it from sulphurous acid, which is produced during the sublimation, and clings tenaciously to the condensed particles. In the wine countries of Southern Europe flowers of sulphur are used on an enormous scale as a cure for the *oidium*, or vine-disease.

warm hand close to the ear, and listen to the peculiar cracking noise which it utters. This sound is due to the fact that the heat of the hand expands that part of the sulphur which is in immediate contact with the warm surface; but as sulphur is a very bad conductor of heat the adjacent parts are slow in acquiring the same temperature; and hence the expanded portion is torn away from the mass with a sudden crack.

When a stick of sulphur is rubbed with a piece of flannel, or even with the naked hand, it

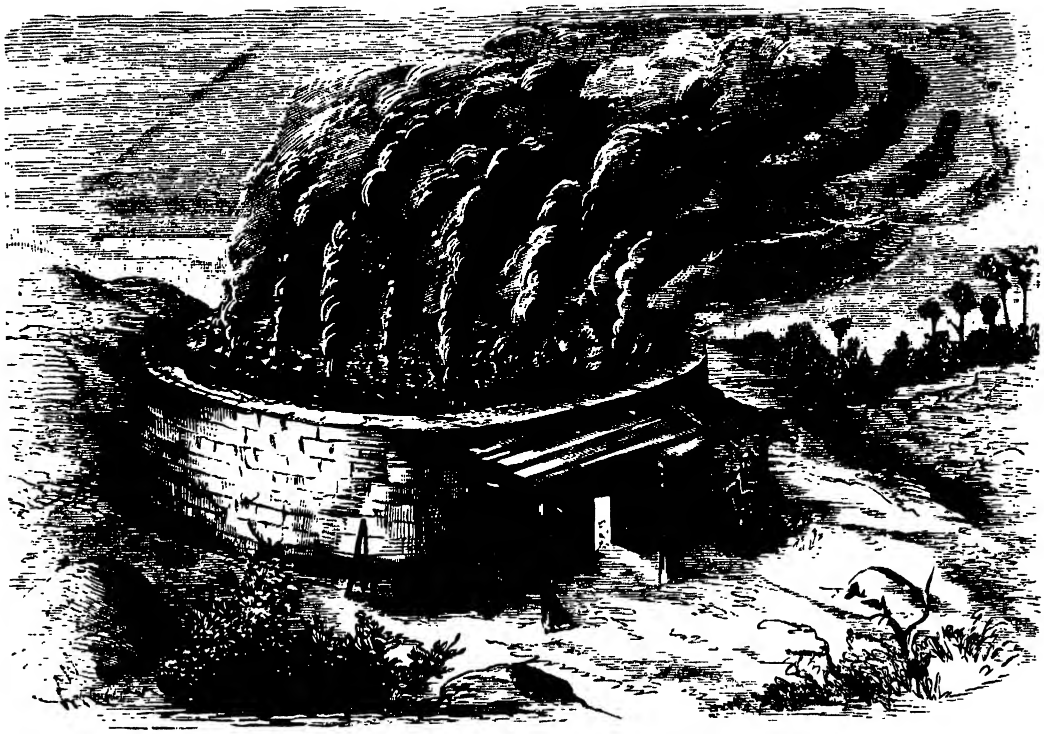


Fig. 7.—Calcarone, or Sulphur-kiln, in Sicily.

In the process of refining sulphur the fumes from the retort will condense as "flowers" only so long as the walls of the condensing chamber are moderately cool. When they become heated the sulphur melts, and, trickling down, settles at the bottom of the chamber as a layer of liquid. It is a general law that when a body passes from the condition of vapour to that of liquid or solid it gives out heat which was previously latent in the vapour. Consequently, during the distillation of the sulphur, the temperature of the condensing-chamber rapidly rises, and the production of the solid flowers of sulphur—a kind of sulphur-snow—is prevented. The distilled sulphur is run off in a molten state, and cast in moulds, forming the yellow sticks known as *roll sulphur.*

It is curious to hold one of these sticks in the

acquires the power of attracting light bodies, just as a piece of amber attracts them when similarly excited. Sulphur is therefore said to acquire negative or resinous electricity by friction. Otto von Guericke — the famous old burgomaster of Magdeburg who devised the first air-pump—took advantage of this property in the construction of a crude electrical machine. Melted sulphur was poured into a glass globe, and the glass broken, whereupon a ball of sulphur was obtained. This sulphur sphere was then mounted upon an axis, and caused to rotate against the hand, which acted as a rubber. Rough as this contrivance was, it yielded electricity more freely than any previous instrument, and thus did good service in the progress of electrical science.

Sulphur in the form of sticks and cakes is

frequently known in commerce as *brimstone*. This word is simply a corruption of the Teutonic *Brennstein*—the stone which burns—and is curiously like the German name for amber, *Bernstein*, a word which has the same meaning. Both the brimstone and the bernstein are combustible minerals. Moreover, it is generally supposed that the idea of combustibility lies at the bottom of the word *sulphur* itself, since this is said to be an awkward compound of the Latin *sal*, salt, and the Greek *pur*, fire—sulphur being, therefore, the salt which burns.

It is, of course, the ready inflammability of sulphur which causes it to be so largely used in the manufacture of gunpowder, fireworks, and lucifer matches. When the sulphur is heated, with free access of air, it burns with a lambent blue flame, producing by its union with the oxygen of the atmosphere a pungent, suffocating gas, called *sulphur dioxide*, or *sulphurous anhydride*. When dissolved in water, this body forms a powerful bleaching agent, and hence the common practice of discharging a fruit-stain from a handkerchief by holding it, in a moistened state, over a burning match. On the same principle, burning brimstone is largely used in bleaching straw-plait, silks, and flannels, being preferred to chloride of lime, inasmuch as it does less damage to the fabric.

A vast quantity of sulphur is daily consumed in this country for the purpose of forming sulphur dioxide, to be afterwards converted into *sulphuric acid*, or "oil of vitriol," used so extensively in many manufactures. Formerly the sulphur was burnt in its free state, but at the present time very little of this "brimstone acid" is manufactured. The great bulk of our sulphuric acid derives its sulphur from the mineral called *iron-pyrites*—a compound of sulphur and iron, containing more than half its weight of sulphur. Large quantities of this pyrites are raised in the Vale of Ovoca, in County Wicklow, and are brought into the market as "sulphur ore," while still larger quantities of pyrites are imported from Spain and Portugal.

Iron-pyrites is only one of a large series of minerals known as metallic *sulphides*, or combinations of sulphur with various metals. When it is mentioned that such minerals form a large proportion of the ordinary ores of copper, lead, silver, mercury, and antimony, it will be seen that sulphur is extensively distributed through nature in this form. But the sulphur occurs not only as sulphides, but also as *sulphates*—that is to say, as compounds of sulphur, oxygen, and a metal. Of these native sulphates, the most important is *gypsum*, or sulphate of lime, a compound of sulphur, oxygen, and calcium. It is a suggestive fact that this mineral is generally associated with deposits of native sulphur. There is, indeed, little doubt that native sulphur has in many cases been formed from gypsum by the reducing action of decomposing organic matter.

From what has been said above it will have been gathered that sulphur occurs in the mineral kingdom under three distinct forms: first, as native or virgin sulphur; secondly, as metallic sulphides, or combinations of sulphur with metals; and thirdly, as sulphates, or oxidised compounds containing metallic bases. Sulphur also exists in various organic compounds—some of vegetable, others of animal origin. Thus it is found in oil of mustard and in various products of other plants belonging to the great order of the *Cruciferæ*, or the cabbage order; while its existence in certain animal products, such as albumen, is sufficiently evident from the common observation that a silver spoon blackens when used with a boiled egg, the blackening being due to the formation of a sulphide of silver. It is beyond the purpose of this paper, however, to refer at length to the organic compounds which contain sulphur; but enough has already been said to show the singularly wide distribution of this element, the important part which it plays in the economy of nature, and the manifold uses to which it is applied in the arts of civilised life.

VORTEX RINGS.

By William Ackroyd, F.I.C., etc.

THE reader may have seen some veteran smoker, who, when so inclined, would remove the pipe from his mouth and amuse his friends by puckering up his lips, and sending out rings of smoke. It is a feat which appears easy enough to the performer, but would-be imitators make long and choking attempts to do it before they are finally successful, and some, indeed, never can manage it.

These latter, however, may console themselves by seeing the rings made in other ways. On a fine calm day, with scarcely a breath of wind, splendid rings may be seen at times rising from the chimney of a locomotive when the driver is letting out short and sudden puffs of steam. These vapour rings are of the same kind as the tobacco-smoke rings, and they are termed in science *vortex rings.*

In a former paper* we gave some particulars of these vortex rings, such as how they might be made, the nature of their motion, and the theoretical use to which they have been put. Since, however, the subject was on that occasion very barely touched on, we propose now to supplement what was then said by giving a somewhat more minute description of vortex phenomena; for this subject, although in its infancy, has become one of no small importance, seeing that vortex motion is possessed not only by the mighty planet whirling through space, but is likewise supposed to be possessed by the tiny atoms of which it is built up.

The whirlwind or whirlpool is the simplest form of vortex motion, and the connection of a columnar vortex of this sort with a vortex ring is exceedingly easy to comprehend. A vortex ring may be regarded as a string of whirlwinds if in air, or of whirlpools if in water, joined end to end, so that if it were possible to break the ring and to stretch it out, we should have a single whirlwind or whirlpool. Or to put the matter in the converse and perhaps simpler way, imagine A, Fig. 1, to be a simple columnar whirlwind or whirlpool, and further imagine it now to be doubled up, and its two ends brought together so as to form a ring, as at B, then B would be a vortex ring. Simple vortices may be created by any rudder-like movement within a fluid, be it water or air, so that a very simple piece of apparatus is all that is required for such a purpose.

Fig. 1.—Illustrating the Connection between a Columnar Vortex and a Vortex Ring.

Knock out the bottom of a common deal soap-box, so that there is nothing now left but the sides and a door on hinges. Let a sheet of drawing-paper be next pinned down on the table, and on this place the box on end. A quantity of black tissue-paper, torn into very small pieces, must now be sprinkled on the white paper in front of the box. Upon now drawing the door smartly to in the direction of the large arrow (Fig. 2), a simple vortex or whirlwind is produced, which is readily shown by the movements of the black tissue paper. It is a miniature whirlwind, differing only in degree, and not in kind, from the tornado and cyclone, which drive heavier objects about with such destructive force; and the reader may form a vivid idea of the devastation worked by these vast aërial vortices, which spring up at particular seasons on land and sea, by supposing each of these bits of paper to represent trees, houses, or ships, which are with the same apparent ease uprooted, blown down, or wafted to destruction. One would think that it is indeed no matter to joke over, but American humour has found something to present in a mirth-provoking light even in the mighty force of a tornado, which is thus described by a Transatlantic paper:—"Yesterday during the gale, while boulders as big as pumpkins were flying through the air, and water-pipes were being ripped up out of the ground, an old Chinaman, with spectacles on his nose, was observed in the eastern part of the town calmly flying his kite—an iron shutter with a log-chain for a tail."

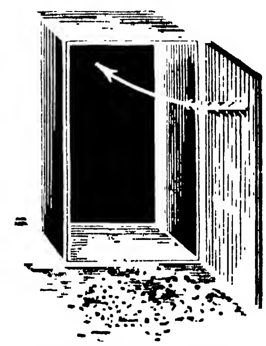


Fig. 2.—How to make a Columnar Vortex.

Leaving simple vortices, we now turn to consider the methods of making vortex rings. Professor W. B. Rogers, of America, nearly a quarter of a century ago, used to make vortex rings by filling soap-bubbles with smoke, and then pricking them. He was also acquainted with the liquid rings formed generally when a drop of coloured liquid is allowed to fall into a colourless one, and he regarded the fluid rings as of the same nature as the smoke rings. These fluid rings, the reader will remember, are obtained by allowing a drop of coloured fluid, like permanganate of potash solution, milk, or ink, to just touch the surface of water when a system of rings is formed, which

* "Whirlpools and Whirlwinds:" "Science for All," Vol. I., p. 40.

travels towards the bottom of the vessel. But perhaps the vortex box method is the best of all for exhibition on a large scale, this box being, as we have before minutely explained,* simply a tea-chest with one side removed and replaced with canvas, while in the side opposite to it there is a round hole for the rings to emerge, which are produced every time the canvas receives a knock. When such a box is charged with smoke the smoke rings produced sail gaily across the room, and look charming if illumined by the rays of an oxyhydrogen lamp. In the latter case great diversity may also be produced by introducing coloured glasses in front of the lamp, so that the advancing rings may be made to appear crimson, yellow, green, or blue, &c.

A method of making vortex rings, which we have not yet spoken of in these pages, is that usually exhibited when "phosphoretted hydrogen" is made. About half a fluid ounce of strong solution of potassic hydrate and ten grains of phosphorus are put into a retort, and heated gently until a flash is seen within, when the beak is immediately placed under the surface of water. The gas begins to come over, and as soon as it comes in contact with the air, ignites spontaneously. As each bubble rises above the surface, and discharges itself into the atmosphere, a flash is seen, and out of the tiny fiery disturbance

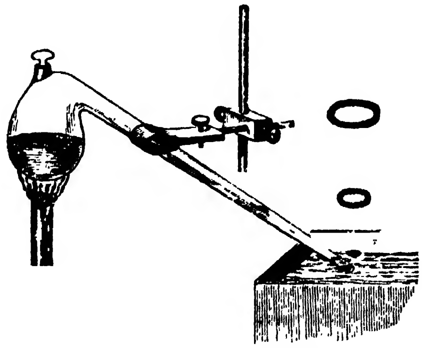


Fig. 3.—Vortex Rings of Phosphoric Oxide.

there is evolved a beautiful white vortex ring, which sails leisurely upwards if not disturbed by air currents (Fig. 3).

Nothing, perhaps, could appear more dissimilar than these various ways of making vortex rings with the mouth, collapsing soap-bubbles, puffing locomotives, descending drops, vortex boxes, and bubbles of ascending phosphoretted hydrogen made in the way we have described. They are probably, however, all very nearly related, for we shall find, on a comparison of what takes place in the last three methods, of which we know most, that they are essentially one and the same, although the agents at work may be different. Let us inquire a little more closely into the way rings are produced in these particular cases.

Vortex-boxes may be made of many forms, either cubical, cylindrical, or approximately spherical. To make the last form one may take a cocoa-nut, and bore a small round hole at one end.

A B C

Fig. 4.—Vortex Rings: a Comparison.

The other end has now to be sawn off, and the contents extracted, so that there is nothing but the hard husk left. Over the larger end a piece of canvas is now fixed (Fig. 4, A). After filling with smoke, the rings as usual are emitted from the small orifice every time the canvas is tapped with the finger. Now, making vortex rings with such a piece of apparatus would be nearly like making them with bubbles of phosphoretted hydrogen, or drops of milk and ink. And this we can make apparent by means of a diagram showing the conditions in each case at a particular moment. Let us see, for example, the exact nature of things when a rising bubble of phosphoretted hydrogen is just peeping out of the surface of the water, as at B, Fig. 4. There is a circular orifice formed which places the contents of the bubble (*c*) in communication with the external air, so that at this particular moment the walls of the bubble form a liquid vortex-box, to all intents and purposes similar to the solid cocoa-nut box. Again, there is the same similarity in the case of a falling drop of milk or ink coming in contact with a surface of liquid as at C, for here, directly the drop (*c*) touches the surface of the water, it is evident that the air which surrounds the drop forms a kind of box with a circular opening, placing the globule or contents of the aërial box in communication with the larger body of fluid below. It is very apparent, therefore, that so far as external form goes, there is a marked similarity in the three ways

* "Science for All." Vol. I., p. 43.

of making rings, the mould in each case being of the same form, although made of materials so widely dissimilar as solid, liquid, and gas, and we shall now see that the vortex motion in each case, although generated by different agents, is managed in much the same way. The contents of the nut-box, for example, are agitated by a knock at the canvas back, which is placed opposite to the circular opening, and the knock in the cases of the liquid and aërial boxes is given by the pull of gravity, and, as before, at the back part which is just opposite the circular orifice. The latter point may not be so evident, and therefore we shall proceed to make it somewhat more clear.

First, then, as to the bubble of phosphoretted hydrogen at B. The pressure on its walls is very unequal, and for the simple reason that the deeper one descends into a liquid the heavier is the weight of superjacent liquid that has to be borne, and as pressure in such cases acts in all directions, it follows that at *c*—viz., at the bottom of the bubble—we have the greatest pressure, and less and less at any point on each horizontal zone, as we ascend towards the orifice. The greatest pressure at *c* corresponds to the knock at the canvas in the case of A, so that the contents of the liquid-box are sent out with a ring-vortex motion, and a chemical change simultaneously occurring, the vortex ring is made evident by means of the white smoke of phosphoric oxide which is formed. It also follows that where we have a falling drop, as at C, there is the greatest push at *c*, because while each part of the drop has hitherto been falling with the same speed, immediately it comes in contact with the liquid below, the parts of it nearest the opposing fluid are retarded, and we have consequently the greatest speed or push at *c*, a point opposite the circular orifice of the aërial box. It is quite plain, therefore, that in these three cases we have taken the trouble to examine, and which seemed so dissimilar at first sight, we have essentially the same plan and operations at work.

Perhaps most attention has been paid to the formation of liquid vortex rings by Tomlinson and Deacon. Tomlinson called them "submersion figures," a name which involved no theory as to their formation or structure; Deacon, like Rogers, considered them to be true cases of vortex motion, arising not from *diffusion*, as Tomlinson maintained, but from the ordinary motion which follows the impact of two bodies--and, by way of illustration, he refers to the "cold metal 'ring'" formed when a smith's chisel-head has been "burred" out, and recurved by blows (Fig. 5). With regard to diffusion, the same observer remarks that although it may modify, and thus, in one sense, may be said to create these phenomena, yet diffusion really is the cause of their destruction. The striking analogy which the writer has shown to exist between the way in which these liquid rings are made, and the ways employed to make rings with the vortex-box and bubbles of phosphoretted hydrogen, certainly gives strength to the views of Rogers and Deacon, and probably any differences of opinion that have arisen on this point may have been caused by the peculiarity which appears to be possessed alone by these liquid rings—*viz.*, that inorganic evolution, or growth of the single ring at first formed into a series of others. To see this once more, dip the tip of your pen, charged with ink, into water, or allow a drop of milk just to graze the surface of the water, in each case it will be found that the first ring formed develops into several others on its way to the bottom of the vessel. In pointing out what one has to look for, Deacon has employed the diagrams

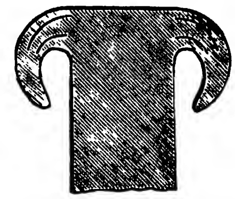
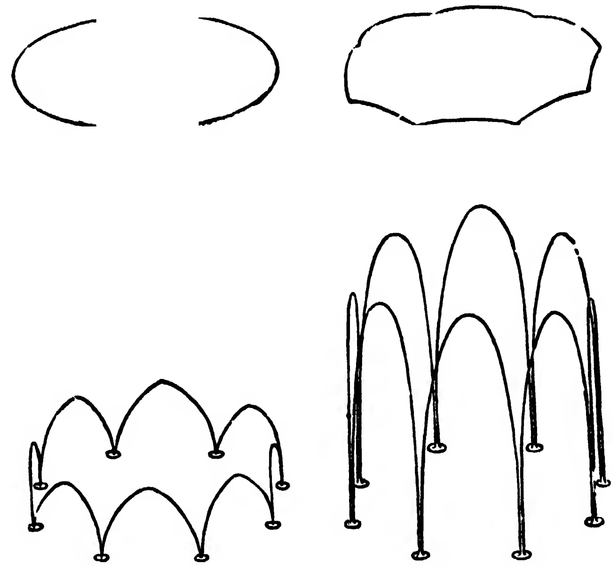


Fig. 5.—"Burred" out Head of Smith's Cold Chisel.



C D

Fig. 6.—Growth of a System of Rings.

A—D, Fig. 6, to illustrate the growth of a system of rings. When the drop first falls, a miniature vortex ring, A, is formed. The next change is exhibited in B, which illustrates the formation of nodes, varying much in position and number,

according to circumstances. While the ring is still descending, these nodes begin to develop secondary rings C, which are again shown at an advanced stage in D, where it will be perceived that the centre of each secondary ring is connected with the others on each side of it by means of delicate arches. Occasionally a form is seen, of which Fig. 7 is an illustration. Here the secondary rings are connected by a delicate film, which, in the upper part, contracts, into a narrow tube, and is surmounted by a bell-like cover. This form is of much interest and beauty, and we cannot do better than quote Deacon's words concerning it :—"Working with a very attenuated solution of permanganate of potash, the secondary rings resting on the bottom of the beaker, or wholly suspended in the water, it strikingly resembles a living animal like a sea anemone. As all this structure is formed from one single drop, its extreme tenuity can be easily imagined. The resemblance of these structures to organisms is more than in form. Whilst they are growing they are, so to say, 'alive,' bright colours, and clearly-defined objects. When they cease to grow their 'life' ceases too; they become dull, flaccid, nebulous; they quickly dissolve into the surrounding space—they die."

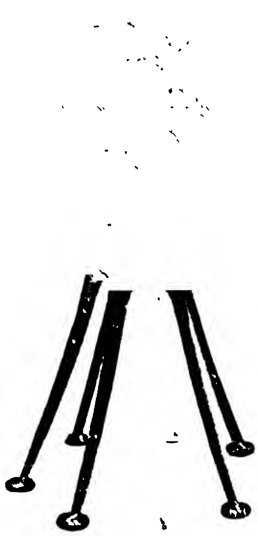


Fig. 7.—Another Form of Vortex Ring.

In obtaining these phenomena, care has to be taken to deliver the drop gently and well-formed. If it fall from too great a height, and consequently have too much impetus, the results obtained are far from satisfactory—a mere cloud, or two or more very small rings.

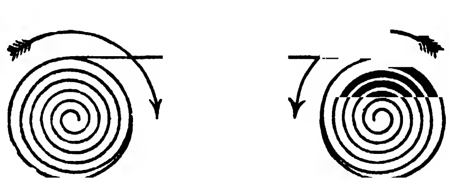


Fig. 8.—Motion of a Descending Vortex Ring.

With regard to the vortex-motion that will be readily understood, it is like the motion of smoke-rings, *i.e.*, the inner portions of the ring move in the same direction as the whole ring. Let Fig. 8 represent a section of one of these rings as soon as it is formed, then the large arrow will represent the downward direction of the whole ring, and the lesser arrows the vortical motion of its parts. In water this motion ceases almost entirely, and while the whole ring is descending bodily, water is displaced, and a current, due to the displacement, flows upwards through the ring, giving rise, no doubt, to the delicate filament which generally forms the train of such a ring. It will be found that the secondary rings give rise, as a rule, to the tertiary, and these to a quaternary series, and so on, according to the depth they have to go, and the quantity of material in the descending vortices.

We may turn now to the theoretical considerations which have arisen from a study of vortex rings. Two smoke-rings when sent against each other bounce and vibrate like india-rubber rings, and are not shattered into a shapeless cloud, as one might reasonably expect, but rebound and quiver in the most wonderful manner. In this experiment the modern physicist sees a picture of what he supposes to be happening millions of times per second

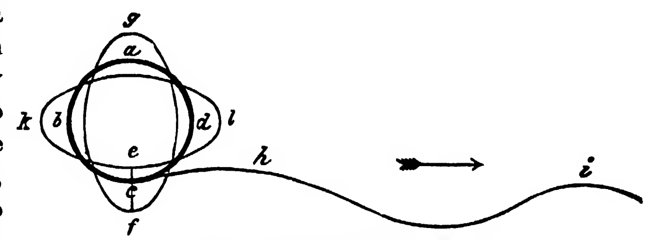


Fig. 9.—A Vibrating Vortex-Atom.

to every tiny vortex-ring* which constitutes an atom of the air we breathe. Under no circumstances could the jingle of this atomic warfare be heard by organic beings, but the vibrations set up do certainly, under certain circumstances, indirectly affect one of our sensory organs—*viz.*, the eye. We may profitably spend a few moments in seeing how this is managed by some individual vortex-atom. Let us single out one from the myriads of vortex-atoms which are jostling each other in a flame, and watch its behaviour with the mind's eye. The ring, *a*, *b*, *c*, *d* (Fig. 9), may represent it. After each of its numberless encounters it vibrates intensely, altering its shape like a quivering smoke-ring, so that we may readily conceive it to quickly elongate into the ellipse *g f*, and directly after into the ellipse *k l*. During this operation, executed in much less than the billionth

* "Science for All," Vol. I., p. 43.

part of a second, and being regularly repeated, it will be seen that a given portion, *c*, of the ring will make excursions up and down through the distance *e f*, and there will be a succession of ether-waves, created like *h i*. If we were also to consider the action of each moving point in the vortex-atom we should find it to be a source of ether-waves in the same way, and when we consider, moreover, that in the flame there is a countless number of vortex-atoms, all behaving somewhat similarly, it is evident that such a flame is a vast source of ether disturbance, each wave of which, if it be within certain limits of length, creates in the eye the sensation of light. The length of the ether-wave which disturbs the retinal rods is very much greater than the diameter of the vortex-atom which may have produced it, so much longer, in fact, that in this respect Fig. 9 is far wide of the mark, as the length of *h i* ought, roughly speaking, to be a thousand times the distance *a c* or *b d*.

One word more, and then we have done. Poetry and Science are said to have little in common, and a poet's licence would certainly have never led him to regard the light of Sirius as the music of vibrating vortex-atoms. But Science affirms it of this, and a great many other stars, so that we may exclaim with Lorenzo :—

> "Look, how the floor of heaven
> Is thick inlaid with patines of bright gold;
> There is not the smallest orb which thou behold'st,
> But in his motion like an angel sings."

THE ANCIENT AND MODERN ANIMALS OF SOUTH AMERICA.

BY PROFESSOR P. MARTIN DUNCAN, F.R.S.

DURING the last geological age, and just before the time of man, animals of vast dimensions lived in all parts of South America, or rather in the zoological province of Austro-Columbia. The nature of distributional provinces has been described already,* and it has been noticed that South America, as far north as the elevated table-lands of Mexico, is a very important example. Its limits are the sea to the east, south, and west, and the table-lands to the north—limits established by Nature during the last changes in the earth's crust, and which restrict the roaming power of most of the animals which live within the boundaries. Certain animals belonging to the orders Edentata (sloths, armadilloes, ant-eaters), Rodentia (hare and rabbit order), Tylopoda (camels and llamas), and Quadrumana (or monkey order), live in the province and characterise it: that is to say, they are not found anywhere else on the surface of the earth, and cannot move out of the province, because the physical geography is of a kind that cannot be overcome by their particular methods of locomotion. In the last chapter of the history of the earth there was a distributional province covering much of the same ground, and it had characteristic animals which are extinct and were gigantic. The question is, what relation did this old province and its animals bear to the present? The answer is not so readily forthcoming as it was in respect of Australia,† because at the present time Austro-Columbia is sub-divided, in a most remarkable manner, by natural limits into minor distributional provinces which do not appear to have existed so definitely formerly. It is necessary first of all to consider these separate parts and their characteristic animals.

When the Europeans first visited the northern parts of South America—south of the region of the table-lands of the Isthmus of Panama—they saw a country of virgin forests, often impassable, noble rivers flowing between banks crowded with gigantic timber, and here and there open grassy spaces. Leaving the very high land and mountain ground out of the question, the forest region covered the countries watered by the Orinoco, Amazon, and other great rivers, and also what is now Colombia, the Guianas, Brazil, and much of Peru and Bolivia. A hot and moist climate favours the growth of vegetation, and the great trees of the forest and the dense underwood, are rendered all the more interesting by the hanging and entwining parasitic plants.

The eye sees a vast, slightly undulating sea of tree-tops from any unusual height, and weeks may be passed in voyaging down the great rivers between the woodlands of the banks. There are swamps by the sides of some of the great rivers, and they are often the only open or treeless

* "Science for All," Vol. IV., p. 334.

† "Science for All," Vol. IV., p. 336.

country, but usually their banks teem with vegetation. The huge trees fall and rot and disappear, others succeeding them. Nothing but the encroachment of the rivers during their occasional change of course or extension, fire, and the sea have any influence on this land of trees.

Far away to the south, towards the province of La Plata, the great forest becomes broken up by large patches of grass land, and still further, the trees become scarcer and scarcer, plains, at different altitudes, succeeding. These are of vast extent, and reach from the Atlantic to the Andes. They are intersected by rivers, and whilst the majority of these pampas may be compared with the North American prairies, and are grassy and treeless, many thousands of square miles of plain are sandy, or the soil is impregnated with salts, and is barren towards the south.

Gradually the fertility of the plains diminishes, and in Patagonia, on the Atlantic side, there are vast districts of gravel, sand, swamp, and salt lake, extending to the Straits of Magellan. So that, in a wide and general sense, South America, not considering the mountain ground and the Pacific side of Patagonia, consists of three districts—the first, forest land; the second, grassy and salt plains; and the third, the hungry, sterile gravel and saline ground of Patagonia.

It must be remembered that the rivers in many instances are vast, and utterly impassable by many animals. Now, each of these great districts forms a little distributional province: each has its fauna or characteristic animals. One of the most remarkable animals of the forest land of the northern parts of South America is the sloth (Fig. 1), for it is peculiar to those regions, and is not found beyond them. The name was given to a number of small-headed, tailless, and very hairy, long-legged creatures, which live amongst the boughs, moving, however, under them by hanging back downwards. Their excessive slowness of movement by day, when they appear dazed with light, and their usually being then found sound asleep by the hunters, gave the name. But really they are nocturnal in their habits, and can move very rapidly, if so inclined, by means of their long arms and legs, assisted by very long claws. They are vegetable-feeders, and usually attack a

Fig. 1.—Group of Sloths.

cecropia tree, and gradually devour all its leaves before passing to the next. When seen in captivity the sloths really deserve their name. Possessing no teeth in the front of the mouth, where the incisors of other animals occur, the sloths have the face, as it were, cut short, and the back teeth grow from their roots, and wear away persistently at their crowns. Their snub-nose is in front of a broad pair of cheeks, the cheek-bones project, lovers have to descend and crawl, and it is done with apparent difficulty, the weight of the hinder parts of the body being maintained on the outside of the sole of the foot. This turning in is, of course, of great advantage in clinging to boughs whilst hanging, but it impedes locomotion on land. The ankle-bones are firmly united, but one—the astragalus (the bone which in large running animals is jointed with the ends of the bones of

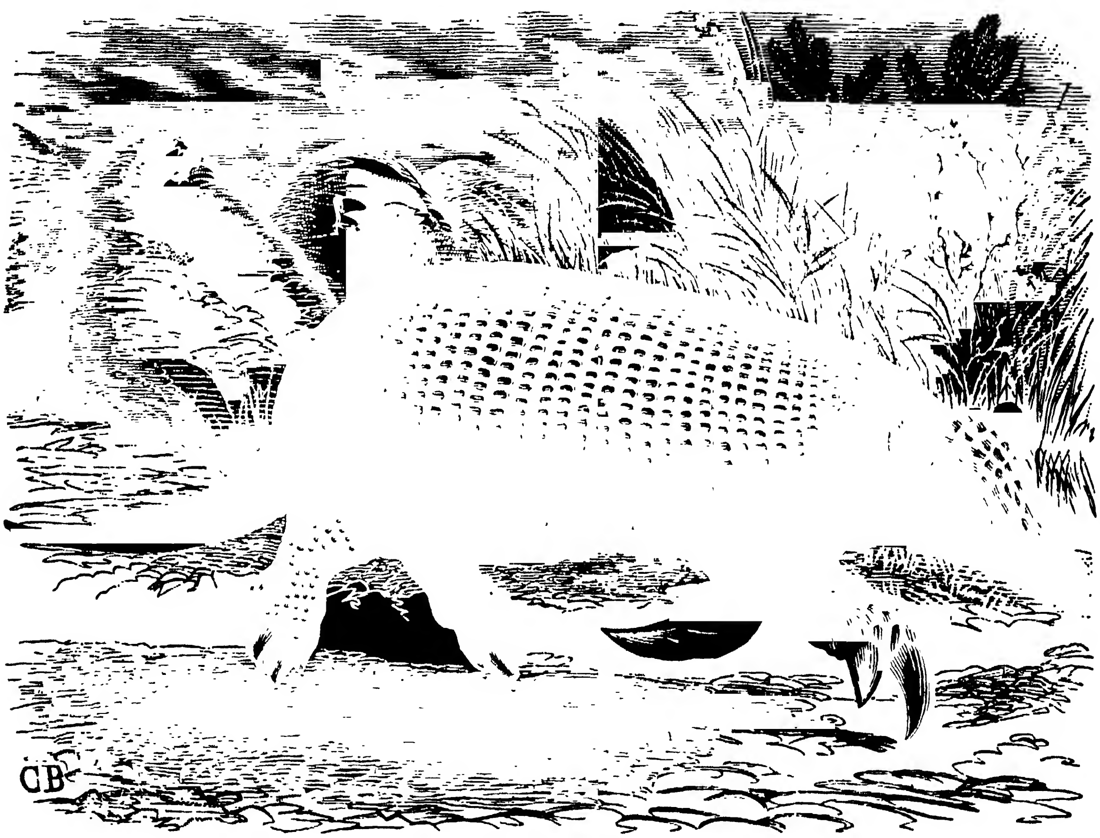


Fig. 2.—The Giant Armadillo.

and there is a downward projecting portion which protects, as it were, the lower jaw from a blow. As great mobility of the head is required when the sloth is feeding, the neck is long, and the backbone contains an unusual number of vertebræ. But the peculiarity which strikes everybody, is the great length of the fore-limbs, and the manner in which two, or in some kinds three, huge claws are folded forwards on the palm. A kind of bony covering environs the claws, where they are attached to the bones of the fingers, and this is necessary in the sloth, for a blow at that spot would destroy the nail and stop the creature's movements. The long legs end in ankles which appear to be turned in. Very rarely these tree-

the legs)—is not included. The outer or small long bone of the leg, fits into a cavity, or pit, in the outer part of the upper surface of this bone, and thus prevents any twisting outwards of the foot. It favours the opposite movement, and there are two powerful muscles which tend to produce the in-bending.

The sloths belong to an order of mammalia called Edentata, and the term relates to the absence of front teeth. From their slow movements, they are called Tardigrada, and there are two families of them—the sloths with three claws on the fore-limb, and those with only two.

These interesting animals are, and must be characteristic of the forest land of the Austro-

Columbian province from the very nature of their restricted locomotion. Moreover, they die off if the forest is diminished, and could not live on the plains or amongst rocks.

A great number of South American animals are more or less covered with a hard, bony crust, which is separated into bands passing over the body and tail, and have shields placed over the head, neck, and hinder parts. These armadilloes have short legs and powerful claws, protected as in the sloth, and useful for burrowing into the ground. The head is rather long, but broad at the back part, and there are no front teeth, the back and side ones being numerous, single, and constantly growing upwards as their tops wear off. From ten inches to a yard in length, these armoured animals have powerful fore-limbs, with claws and a collar-bone. The hind limbs have a large bone projecting backwards from the ankle, and this heel bone is of great use in the squatting position, when the creature is scratching the earth with its fore-claws. The tail is large and well covered, and is also useful in this respect (Fig. 2).

Although these armadilloes cannot mount trees, but live beneath their shade and burrow into the ground, and are eaters of vegetables, as well as of flesh and insects, they have several points in their anatomy which cause them to be ranked nearer the sloths than to any other animals which burrow. They are Edentata, of the genus *Dasypus*, so named from the shape of their feet. The great armadillo inhabits Brazil, the northern parts of Paraguay and of Surinam. It likes the forest, and is never found far out in the plains. The tatouay has the same geographical range, and its claws, as in the instance of the great armadillo, are protected at their junction with the bones of the fingers with the same kind of case as is noticed in the sloths. The six-banded armadillo, a very active little kind, differs somewhat in its anatomy from the others just mentioned, by having two teeth in front, and the fore-arm cannot move the wrist up and down, or rotate, as it does in the others and in the sloths. It is a carrion-eater in Brazil and Paraguay. A hairy armadillo is smaller than the last, and is found in multitudes on the plains or pampas, where it enjoys the flesh of the dead horses. Another, the pichiy, a handsome little scaled creature, burrows with amazing rapidity in the waterless regions of the sand-dunes of Chili and Patagonia, and extends also farther north to the pampas. The curious but beautifully ornamented armadillo called the ball armadillo, which walks on the tips of its great claws, and rolls itself up after the fashion of a woodlouse, lives in Brazil, Paraguay, and Buenos Ayres, and is the contented companion of the hosts of monkeys of the forest. For whilst the others of this armoured group with long tails, suffer from the teasing propensities of these active animals, the little tolypeutes, rolling itself up, presents nothing to lay hold of, and the mischievous quadrumana pay it but little attention.

Although the armadilloes, as a group of animals, live in the forest, out on the plains, and even on very dry ground—that is to say, under very varied physical conditions—they are essentially South American, and characterise the province as it is now. They are not found anywhere else on the surface of the earth.

Allied to the armadilloes are some very remarkably-shaped animals, with very long body, tail, hair, snout, and tongue. The head is long and narrow, the tail, very bushy, is flattened from side to side. When standing, the fore part of the body is highest, and the very powerful limbs end in claws. It rests on the sides of its fore feet, like the sloth, but the hind feet rest flatly, and support the body. Hence, the fore-limb is twisted, as it were, and is capable of much motion. This is the great ant-bear. It is, however, an edentate animal, and not a bear. It lives on ants, whose nests it breaks up with its claws, and then protruding its very long tongue, covered with a sticky moisture, draws it back covered with the angry little insects into the mouth. A very slothful and solitary animal, it reaches the length of four feet and a half; the tail is longer than the body. It lives in all the warm and tropical parts of South America, from Colombia to Paraguay, and from the shores of the Atlantic to the foot of the Andes. Its favourite resorts are the humid forests—but it does not climb—and the swampy savannahs, the banks of rivers, and the sides of pools. The animal is without teeth, but it has a bony palate. The collar-bones are imperfect, but the claws are as remarkable as they are in the sloths and armadilloes. They are grooved beneath, and the great middle claw especially, is protected by an expansion of bone from the last finger bone. This envelops the base of the claw, except quite underneath, leaving the tip free to perform its office, without endangering the tender bone. Another ant-eater is the tamandua, and it leads an arboreal life, having a tail stout at its root, round, and tapering, and minutely scaled. The animal, were it not for

the long head and tail, is not very unlike a sloth. The tail is prehensile, and the claws of the fore-limb are strong and turned in. Finally, the two-toed ant-eater is a little animal having a prehensile tail, and living up trees in the forests of Costa Rica, Honduras, and Brazil. They have two large claws on the fore-limbs, the others being hidden under the skin and muscle, and there are four claws to the hind limbs. Not larger than a squirrel, the little body ends in a long, useful tail, by which the animal hangs like a monkey. It is an insect-eater, and uses its long, sticky tongue to catch its prey.

The anatomist has no difficulty in distinguishing these ant and insect eating animals from others, and in classifying them with their nearest allies in point of construction—the armadilloes. Thus the sloths, armadilloes, and ant-eaters are among the Edentata of the South American province, and characterise it. Did these groups of Edentata also characterise South America when it was a natural history province during the last geological age? The answer is that there were living at that time gigantic and small forms of sloths, armadilloes, and ant-eaters, and that they were associated with other characteristic animals. The deposits on the floors of caves in the Brazils contain bones which had been washed in there when the drainage of the country was different to that which now prevails, and some of them have been successfully compared with those of existing sloths and armadilloes.

Bones of an ant-eater, gigantic in size, and belonging to an extinct genus called *Glossotherium*, were found in the deposits in the caves which included the remains of the sloths and armadilloes. The remains of the last-named animals have also been found fossil in the pampas, or rather in the red earth which underlies the surface of the ground there. Hence, in the last geological age, forest land and plains existed, and were tenanted by sloths, armadilloes, and ant-eaters—Edentata of the same genera, and probably, in some instances, of the same species, as those which live in similar localities at the present time. Some of the fossil forms were gigantic, and others were small. The huge creatures have died from off the land; but many of the smaller were the ancestors of the present edentates. A great armadillo-like animal, called *Glyptodon*,* lived in the last geological age with the true armadilloes of those days, and it has become extinct. It was a proper associate of the still greater edentate which will be noticed presently. Owen considers that a specimen of an almost entire skeleton and outside armour belonging to one of these extinct armadillo-like creatures which is in the British Museum, belonged to a small animal of the kind. It measures nine feet in length, and the armour of the back is five feet long and seven feet across, following the curve at the middle of the back. These edentates were worthy of the name, and the principal difference between them and the modern forms is, that they had no bands or joints in their coat of mail, for the purpose of bending the body, or rolling up into the shape of a ball. The great body-armour was in one piece, and was covered with a profusion of elegant ornamentation. There was a plate of solid skin scales on the top of the head, and the tail was a marvel of encasement within a bony-looking tissue, beautifully sculptured in patterns and bosses, curious in their symmetry, or furnished with spines, which made it resemble an architectural spire. Great limbs were added, and the necessary heel-bone projections were there. The front teeth were wanting, and the side teeth or molars, eight in each jaw, grew persistently, and had a curious fluted or sculptured appearance on a side view. Hence the name of the genus, Glyptodon. Several species existed, but they have all disappeared from off the earth. Equally huge in dimension was another armadillo-like edentate, but it appears to have had greater resemblance to the banded armadilloes than to the glyptodons. It was about three feet high and eight feet long.

There were other edentates in those former times which were not only vast in their proportions, but singular in their method of life. They were amongst the largest of animals, and although extinct and found in the fossil condition, they must be associated with the living sloths, armadilloes, and ant-eaters in the order Edentata, on account of much similarity in the construction of the skeleton; but they do not belong to the same families as the recent Edentata.

Two of these huge animals of the past, have attracted much attention, and there is a skeleton of one, the megatherium, in the British Museum, and of the other, the mylodon, in the Hunterian collection of the Royal College of Surgeons.

The *Megatherium*† was at least eighteen feet in length, and had a small head, long neck, huge body, vast hind quarters, and a great tail. The fore limbs were long, and the huge hind feet had great heel-bones, which enabled the vast thighs and leg-bones to assume the squatting position, when

* *Glyptodon*, sculptured tooth.

† Great beast.

the animal tore down small trees and great branches with its clawed hands. Huge as was the animal, it was a vegetarian. It had a small amount of brain, a great face, and the front of it was produced, so that the tongue rested on a grooved lower jaw. There were no front teeth to this curious skull, and its possessor probably used a long and extensible tongue, after the manner of the modern giraffe, in obtaining its leafy food. A considerable downward bony projection occurs from the cheek-bone, and it probably, as in the little tree-sloth, in which it exists also, was useful in protecting the jaws from blows. Great shoulder-blades were attached to the skeleton, and also collar-bones, so that the megatherium had almost as much freedom in the movements of the arm as a man. Moreover, the wrist was so fashioned that the fore-arm could bend up and down, or become prone and supine. The fingers ended in claws of great size, and the same kind of bony case which is seen to protect the root of the nail in the sloth existed in a greater degree in the megatherium. The position of the fore-limb and hand when the megatherium walked, does not appear to have been like that of ordinary mammals, but it resembled somewhat that of the sloth. There was a turning in of the bones, and a greater or less disposition to rest on the outside of the hand, and not on its palm. The ribs contained a great body cavity, and the haunch-bones were enormous in their width. As regards the foot, it was made upon the same general plan as that of the sloth, but it was huge and clumsy, and adapted to support the vast weight of the animal. The teeth, in the sides and back of the mouth, grew after the fashion of those of the sloth tribe, and differed somewhat in their construction from those of the recent animals. So far as the skeleton of megatherium is concerned—and no other parts of the animal have been discovered—it is comparable in a remarkable degree with that of a tree-sloth. But the special peculiarities of it, indicate a sloth which moved slowly, heavily, and sedately on the ground, and which tore down trees or dug them up by their roots.

This huge creature had bones on a larger scale than those of the greatest terrestrial animal of the present time. The thigh-bone was three times as thick as that of the largest elephant, and the heel-bone stuck out backwards for nearly half a yard. The fore-foot was three feet in length. A gigantic vegetarian, and very harmless to other creatures, the megatherium probably had a longish snout, besides a very long and useful tongue.

The mylodon* was smaller than the megatherium, but it greatly resembled its huge fellow-dweller in the ancient forests. It was about eleven feet in length, and had a small head, no front teeth, a process from the cheek-bone, huge blade-bones and collar-bones, vast forearm-bones, and five clawed fingers. The body was huge, there were great haunch-bones, stout thighs, and the toes, four in number, had claws on two. A great tail added to the similarity between the two extinct creatures, both of which were huge ground-sloths. Mylodon must have had a long tongue, and the bones of the neck permitted the head to be moved readily. Its power of pulling down boughs or tearing up small trees, must have been great. But like the megatherium, it had a small brain, and doubtless lived a simple life of great sameness, and it depended upon the persistence of the forest land for its existence, quite as much as the tree-sloth of to-day does on the preservation of cecropia trees by nature. No descendants of these great ground-sloths exist.

Living in the same forests as the sloths, but not known beyond the region of tropical heat, are the hosts of monkeys of the New World. These are the howlers, the spiders, the capuchins, the saimaris, the owl-monkeys, the sakis, and the marmosets and tamarins. All are readily distinguished from the apes, baboons, and common monkeys of the Old World. Those of the New World have, with some exceptions, prehensile tails, and all have broad noses and different teeth to their allies in Asia and Africa, so that the South American monkeys are distinct, and characterise the northern part of the province.

In the last geological age there were monkeys in the forests with the sloths, and fossil remains of capuchins (genus *Cebus*), of saimaris (genus *Callithrix*), and of marmosets (genus *Hapale*) have been found in the Brazilian cave deposits. Some were those of individuals much larger than the present kind, but they led the same kind of lives.

Besides these there are the remains of a large monkey whose bones cannot be identified in shape with those of any living kind, but it was South American in its peculiarities. It belongs to the extinct genus *Protopithecus*. Mr. Darwin was struck with the number of rodents or gnawing animals which live in the pampa regions, and, indeed, they are common everywhere in South

* *Mylodon*, mill tooth.

America, but certain species and even genera are restricted to one province. Thus, amongst the Caviidæ (cavies) there is a creature called the *capybara,* and it is the largest of all existing rodents, some specimens measuring over four feet in length. It is a stoutly-made animal, with a large head and a blunt muzzle, and it has small ears and no tail. The limbs are of moderate length, and the toes are webbed. It is more pig-like than others, and it is called water-pig (*Hydrochærus*). These large rodents frequent the borders of the lakes and rivers, and formerly lived in the islands in the mouth of the River la Plata, swimming in salt as well as fresh water. They never wander from the water-side, and show a marked preference for large rivers, and they live amongst the reeds and other fringing plants. They dive and swim, and carry their young on their back, and appear to feed by night more than by day.

Its nearest ally is the Patagonian cavy, a rodent very hare-like in appearance, and nearly three feet in length, and weighing from twenty to thirty-six pounds. It has a short tail, pointed ears, and thin legs, and inhabits Patagonia as far south as 48° S. lat., and extends northwards as far as the sterile country and gravelly plains reach. It is a burrower and is a great wanderer, and Mr. Darwin notices that "it is a common feature in the landscape of Patagonia to see in the distance two or three of these cavies hopping one after the other over the gravelly plains" (Fig. 3).

The restless cavy, probably the wild "guinea-pig," is a common rodent in the neighbourhood of La Plata, and seeks watery, sandy, and forest localities, and its distribution is as far north as Guiana. On the other hand, the southern cavy is restricted to Patagonia.

Another family of rodents is that of the *Agoutis* (Dasyproctidæ), and the species are all restricted within the limits of the great Austro-Columbian natural history province, but they keep to the forest region, haunting the banks of the rivers. The common agouti is from eighteen to twenty inches long, and runs and springs with velocity and ease. Its coarse hair of brown and black, with a white stripe under the body, is longer behind, and gives the animal a bulky look about the hind legs. The head has small ears, and its tail is almost absent, whilst the slender legs have only three toes on the fore-feet. Farther north than where this agouti lives, there is another, which is restricted to Paraguay and South Brazil; whilst a third is only found in the north of Brazil, Guiana, and in several of the West Indian Islands. It has a tail. Another member of this family is the paca, and

Fig. 3.—Patagonian Cavy.

it is shorter than the agouti, and has five toes. Its arches of bone (zygoma) between the cheek and the ear are enormous in size, and are, as it were, inflated. It is a forest dweller, and inhabits the country from the table-lands to Paraguay, burrowing down to four or five feet, and swimming well. Another family, peculiar also to South America, is that of the chinchillas (Chinchillidæ). They are more or less rat-like in appearance, and the species which inhabit the pampas are heavier-looking animals than those which live in the hill country, and which yield the celebrated fur. One of the commonest is the viscacha, and it is not unlike a marmot, and has a longish tail. It has a soft coat of brown hair, more or less grey above, and there are four toes on the fore limbs and three on the hind ones. They live as burrowers in the pampas,

from Buenos Ayres to Patagonia, and are nocturnal in their habits, moving very like the rabbit. The chinchillas of the Andes are more squirrel-like, and their beautiful soft fur is of a grey colour, mottled with darker and lighter tints. The ears are large, there is a tail, and they run very much like mice. Inhabiting clefts in the rocks, they come forth at twilight.

The porcupines which live in trees and have prehensile tails, range over the Austro-Columbian province, and different species live from the region of table-land in Mexico to Paraguay. They are essentially forest-dwellers, and are often twenty inches in length, and the tail is often seven inches long. They climb and cling, and rest securely on the branches with their tails, and are nocturnal in their habits. Their spines are not as large as those of the common porcupines of the Old World, but they afford a protection, and those of the tail are useful offensive weapons. They belong to the family Hystricidæ.

Another family more or less allied to the porcupines has the bulk of its species in the Austro-Columbian province, but some inhabit South Africa and the West Indian Islands. But this remarkable distribution must not interfere with the value of the facts that the ctenomys, or tuko-tuko genus, ranges as far south as the Straits of Magellan, and that the coypu (*Myopotamus*), a large rodent, lives on the shores of lakes, of the sea, and on the banks of rivers. They are capital divers. Other members of this family, which, from their having four molar teeth on each side in each jaw, are called octodonts, are found in Chili and Bolivia.

It is thus evident that amongst the rodents the families Caviidæ, Dasyproctidæ, Chinchillidæ, Octodontidæ, and a sub-family of the Hystricidæ are in the Austro-Columbian province. As Austro-Columbia is the stronghold of many families of rodents now, so the ancient distributional province had a grand fauna of them during the last geological age.

Firstly, in the bone-caves of Brazil Dr. Lund obtained the osseous remains of Caviidæ. Some belonged to the genus *Cavia*, and two to that of *Hydrochœrus*, and one of these last closely resembled the existing capybara, whilst the other belonged to a gigantic species some five feet in length. Then, in the deposits of the pampas the remains of a cavy have been found, and it is probably the same as the Patagonian living species.

Secondly, the same caves yielded the bones of two species of agouti and two pacas, and of these dasyproctidæ, one is a species probably still living; all the others are extinct.

Thirdly, the chinchillidæ left their remains of old in the caves, and an extinct kind of viscacha is found there.

Fourthly, the genus sphingurus, the tree-porcupines of the hystricidæ, had two species during the last geological epoch in Brazil.

Finally, the octodontidæ were an important family during the last aspect of nature before the present, in South America, for two species of tuko-tuko (*ctenomys*), one of which is the same as the existing form, have been detected in deposits by the study of their bones, and also a fossil coypu, not very unlike the living species.

Thus, the old natural history province was characterised by its rodents as it is now; the fossil kinds were allied to those living, and some were absolutely the same. The gigantic size of some extinct ones must be remembered. But besides these fossils there were some which cannot be placed in classification with any genus of the existing Austro-Columbian rodents, yet belong to the special families. The persistence of the particular type of rodents is thus very remarkable in the province, and the present assemblage was clearly foreshadowed in the past, for existing and now extinct species lived together. Now, the history of the discoveries of fossil rodents opens out the idea that the former Austro-Columbian province was more extensive than the present. Thus, in South Carolina, Leidy has found a fossil hydrochærus, and Cope has described two genera of chinchillidæ from the bone-caves of Anguilla, in the West Indies. The fact of existing species of the same group of octodonts or the coypu living in the West Indian Islands, such as the *Hutia Conga* of Cuba, and another from San Domingo, indicates a terrestrial continuity in a late geological age, and a more extensive province; and to complete these remarks on the rodents, there is the highly suggestive fact that there are fossil species of octodontidæ in South America and living species of different genera of the family in Africa.

Amongst the bones found in the red earth of the pampas, is the huge skull of an animal which must have attained the dimensions of a rhinoceros, yet the great bent fore-teeth give it the appearance of a rodent, and this is increased by the size of the bony arches on either side of the face. Considered superficially, this huge skull might have

been presumed to have belonged to a rodent vastly larger than the capybara, and it has been instanced as a proof of the former existence of a gigantic type of an order which still prevails in the province. But careful examination detects differences between the skull and that of the rodent, and shows that in its construction and teeth, taken with the nature of what is known of the limbs, this old remain belonged to a most extraordinary animal with some of the peculiarities of the rodent, of the edentata, and of the ungulata. It thus combined characters of three great groups of animals, whose familiar representatives are the rat, the sloth, and the hyrax or cavy. It is what is termed a synthetic type—one that conjoins several structural ideas and realities. It is called the toxodon, from the bent nature of its front teeth, and is extinct. Long after this toxodon was discovered by Mr. Darwin several skulls and bones of a great species of extinct animal were found in the pampas clay, and which were not without their resemblance to the fossil just noticed. The front teeth were much the same, but some were worn, like those of the rodent, others being flat, as in toxodon. This blunt-toothed rodent had a very massive skull, with crests of bone on it which join the arches on the side of the cheek, so as to hide the brain-case from side view. The lower jaw is very like that of the hare, but it is hung to the skull in a different manner to that of any living rodent. This merotherium had collar-bones, and its shoulder-blade and upper arm bones resemble those of the beaver. Its small leg-bone is jointed with the heel, as in the hare. Its five toes, with hoof-like claws, resemble those of the caviidæ, and it probably had the habits of the capybara. But besides these peculiarities, it has structures which ally it with the edentate and the ungulate hyrax. This is also a synthetic type, and has the Austro-Columbian characteristics.

Mr. Darwin described, many years ago, the curious habits of the guanaco, or wild llama (*Auchenia*), which he distinguished as the characteristic animal of the plains of Patagonia. This camel of the West, as it has been called, has no hump, but it has a head not unlike that of the true camel, and its feet differ slightly also. But it belongs to the same order—the tylopoda, or cushion-footed animals, amongst the mammals. They live in herds of from half a dozen to thirty in each, or more, and roam over the whole of the temperate parts of the continent, as far south as Tierra del Fuego. Another kind, the vicuna, is smaller, and lives in upland regions in the Andes, coming down into the valleys. The domestic llama is a tame guanaco, and the alpaca is a domesticated vicuna, and the wild ones have a great ancestry.

Considering that the rodents and edentata characteristic of the natural history province of South America were represented there in the last geological age, it might be anticipated that the llamas would have been foreshadowed in the past. It is true that remains of auchenia (llama) have been found in the Brazilian caves; but there were other llama-like animals then living which are now extinct, and which in their size bore some relation to the extinct representatives of the armadilloes and sloths. The resemblance to the camels, now restricted to the Old World, of some of these old forms was remarkable, and two genera illustrate this—namely, *Palæolama** and *Camelotherium.*† There was also living with these in the last geological age a huge llama-like animal, which, instead of having two toes to the feet, like the llamas and camels, had three. Its skull was like that of a horse, and the body like that of a gigantic llama. It is the *Macrauchenia*,‡ and it was found in red mud capping the gravel of Patagonia.

Just as the edentata, quadrumana, rodents, and tylopoda characterise the natural history province now limited to the north by the physical boundaries of the Mexican uplands, so some of their predecessors characterised a former province, which, however had a greater extension to the north and north-east. There is evidence that, either in the last geological age or in one before it, there was a connection between some of the West Indian Islands and the mainland, and a free passage up into North America without the present table-lands intervening. Portions of the skeletons of species of megatherium and of mylodon have been found in North America; associated with them were the remains of an edentate called *Megalonyx.*§ Again, in Cuba the remains of heavy ground sloths of extinct genera have been found.

It then appears from the researches of the distinguished geologists of the United States that in the mid-tertiary age there were great ground sloths in the north. Moreover, the llamas once roamed far north, for an auchenia left its teeth in the latest deposits in California, and an ancient tylopod lived in Virginia, Nebraska, and Texas during the middle and later tertiary ages. So the history of

* Old llama. † Camel-beast. ‡ Great auchenia. § Great claws.

the South American province appears to be, that in the first instance it was so united to North America that the largest known animals had free roaming ground from the north to the south, and that there was a land connection with the West Indian Islands. Then a great change occurred. Firstly, an open sea separated the Americas, and the West Indian land became a number of islands. Secondly, upheaval of the isthmus and of the great table-lands occurred, and a natural barrier was established. Thirdly, those changes took place which determined the extinction of the great edentata—the llamas, the rodents, and the other characteristic animals of South America. In conclusion, the reader must be reminded that when the Europeans first visited America, no horses were seen there; yet fossil bones not very dissimilar from those of horses which live in the Old World are found in abundance. Hence the divisions of the present natural history province were not so decided as they are now during the last geological age.

A MUSHROOM.

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The common edible mushroom grows in short, rich pastures, and, as a rule, nowhere else. It has a very pleasant odour, and may be readily distinguished from all other agarics by the following characters: the chief parts being the cap, or top, and stem. The cap is very seldom more than three or four inches in diameter, and its inner substance is white, or slightly pink, moderately firm, and never thin, brittle, or watery. The top of the cap is white, whitish, or pale brown or buff, dry, and slightly flocculose, never smooth, never viscid. The covering or skin of the top depends from the edge as a narrow, regular frill, and if this frill-like edge be taken between the finger and thumb, the top of the mushroom can be entirely peeled. The gills underneath the cap are at first rose-colour, then purple-brown, at length almost black: they are never permanently rose-colour, or white, and never black in a young state. The gills never actually touch the stem. The stem is generally about three inches high, neither solid nor hollow, but lightly stuffed up the middle with a somewhat loose pith. The stem is furnished with a ring round its middle, which becomes ragged with age. The dust-like spores or seed-like bodies which fall from the gills, and to which we shall afterwards advert, are purple-brown, or almost (never quite) black in colour.

The common edible mushroom (*Agaricus campestris*, L.)* is one of the best known and most cosmopolitan of plants. It grows freely in all parts of the world, though more frequent in temperate than in tropical regions. It everywhere grows on grassy plains, commonly the plains of level countries, and in places where flocks of sheep and herds of cattle are pastured, hence the correctness of the Latin specific name, *campestris*, given by Linnæus. Strange to say, the popular name of the common edible agaric is everywhere "the meadow mushroom," and "the mushroom of our meadows," whereas, as a rule, the mushroom never grows in true meadows, where grass is grown for hay, but in short, rich pastures, and on flat downs, where the grass is continually eaten off by animals. The strong growth of high meadow grass would be fatal to the growth of the true mushroom. In addition to the genuine edible mushroom, empirically known by its small size and place of growth, there are numerous varieties of the true mushroom known to botanists, horticulturists, and mushroom-growers. There is a small, genuine, and excellent mushroom, with a brown and scaly top, sometimes found in pastures and amongst the short grass of roadsides. When broken, the flesh of this variety turns to a pale carmine or pink colour. This is the *Agaricus pratensis*, Vitt. There is a close ally named *A. rufescens*, Berk., in which the flesh turns to a much brighter red when bruised or broken. There are two varieties, named *A. vaporarius*, Otto and Vitt., distinguished by minute botanical characters,

* The letters or contracted words after the scientific name of a plant or an animal refer to the naturalist who first published a description of the species, and gave it the designation it now bears. For example, "L." or "Linn." means that Linnæus first made the organism known to the scientific world; "Berk.," that Mr. Berkeley was its godfather; "Schæff." or "Cke." that Dr. Schæffer or Dr. Cooke played that part towards it; "Fr.," that the great Swedish botanist, Elias Fries, did so; and so on.

and there is the woodland variety known as *A. silvicola,* Vitt., with a smooth cap and long, bulbous stem. This form grows in woods, but its botanical characters, and its place of growth, are suspicious. The horse mushroom (*A. arvensis,* Schæff.) is the "field mushroom" of botanists. This plant grows in fields and meadows, and often forms large fairy rings under and near trees. It frequently attains a very large size:—all "gigantic mushrooms" are "horse mushrooms." This form has a tawny, scaly top, and its flesh turns to a yellow or brownish colour when bruised or broken. It is a coarse species, or variety, generally wholesome, but occasionally indigestible and bad. The mushroom of our markets and of professional mushroom-growers has been named *A. hortensis,* Cke. It is generally described as a variety of the true edible mushroom, but it is much nearer in all its qualities to the inferior horse-mushroom (*A. arvensis,* Schæff.). The mushroom of our mushroom beds (*Agaricus hortensis*), whatever it may be, species, variety, or hybrid, has been mainly selected for cultivation for its ready and prolific growth on dung-heaps, and in cellars, out-houses, and dark places. The true pasture mushroom, as a rule, refuses to grow in such positions. There are several other allied species and varieties of mushroom, well known to botanists, with qualities, in some instances, certain, in other cases unknown; but it would be beyond our province to describe them all in the present paper. Occasionally varieties are seen that differ from every described species. Such forms appear to be genuine hybrids. It is almost impossible to describe in words all the shapes and colours which appertain to the true mushroom and its numerous congeners. Coloured drawings are a great aid in the determination of doubtful forms. Accordingly, the reader is referred to the complete series of coloured drawings of the mushroom and its allies (made by the writer of this paper) in the Department of Botany at the new Natural History Museum, South Kensington, London.

Mushrooms, and especially such as are cultivated on mushroom-beds, frequently grow in an abnormal manner, and these forms are very puzzling to beginners. Occasionally they put on a puff-ball character, with gills inside and no stem. Sometimes the gills grow on the top of the cap instead of underneath; at other times the gills form a spongy mass, instead of being regularly disposed in radiating plates from the stem. Sometimes the stem is ringless. One of the commonest aberrent forms is termed the proliferous condition. In this state a second mushroom grows in an inverted position on the top of the original mushroom, and it is by no means uncommon to see even a third mushroom growing on the inverted stem of the second.

The artificially-grown mushrooms of our markets and gardens are certainly not the same with the genuine mushrooms of our pastures. The naturally grown mushrooms of the street vendors are simply the fungi gathered promiscuously by the vendors themselves in fields and plantations. Genuine mushrooms are rarely present in hawkers' baskets. The horse-mushroom, however, frequently appears, together with several poisonous and non-poisonous species (to be hereafter referred to), and easily distinguished by a mycologist. The reason that fatal accidents do not more frequently occur from the consumption of these dubious and often half-putrid mushrooms is that the poisonous properties (when present) are more or less dissipated by the fire in cooking, or neutralised by the salt, pepper, bread, and other articles consumed at the same time with the fungi.

The general proportions of the true edible mushroom are accurately shown in Fig. 1. The parts consist of the cap (*pileus*), A; the gills (*lamellæ*), B; the stem (*stipes*), C C; and the collar, or ring (*annulus*), D. The same parts are shown in

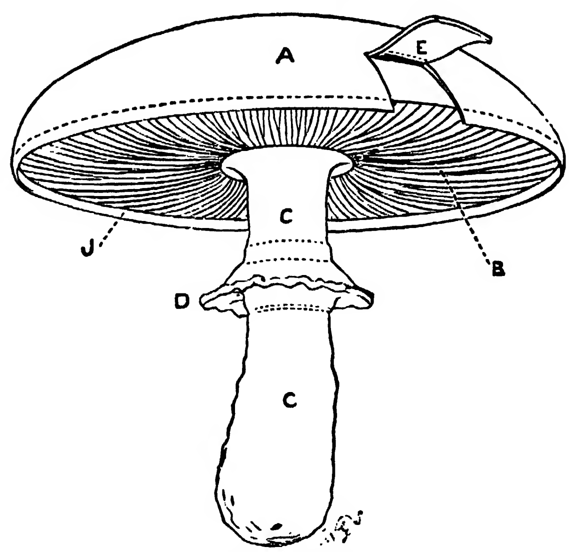

Fig. 1.—The Edible Mushroom (*Agaricus campestris*).

section in Fig. 2. The top of the true mushroom is furnished with a somewhat flocculose cuticle, skin, or veil (*velum*), which readily separates from the flesh of the cap, as at E, Fig. 1. This veil is, during the infancy of the fungus, continuous with the ring

of the stem, and serves to wrap the very young plant in one continuous wrapper, as in the section at F, Fig. 2. The clothy veil or skin is shown at the moment of rupture at G, Fig. 2. The remains of the ruptured veil are generally seen in the form of a narrow dependent margin to the cap, as shown at J J in Figs. 1 and 2. The cap in the mushroom is never thin, watery, and brittle, but always

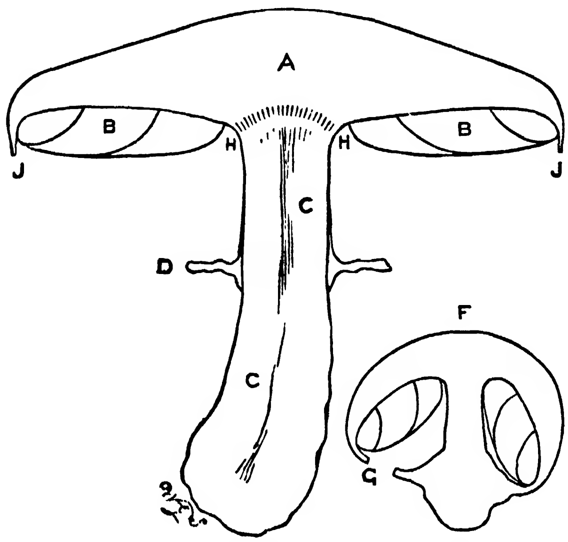

Fig. 2.—Section through a Mature and a "Button" Edible Mushroom.

firm and fleshy. The gills are somewhat crowded together, at first whitish, then rose colour, at length dark purple, brown, or almost black. The gills are sub-deliquescent, but never truly deliquescent. A point of considerable importance in the determination of the true mushroom is the presence of a small channel round the top of the stem, at the point of insertion of stem into cap, seen at H H in Fig. 2. In the true mushroom the gills do not touch the stem, and the stem readily breaks away from the cap, leaving a hollow at the point of insertion. The stem of the mushroom is stuffed, neither solid nor hollow, but loosely packed with a cottony pith. The collar round the stem at D D (Figs. 1 and 2) is one of the characters upon which the correct determination of the mushroom depends, and the absence of a collar is a fatal objection to any mushroom-like fungus. A true mushroom is always dry, never wet or viscid. It also has a pleasant odour, very different from the nitrous or offensive smells peculiar to some of the fungi which resemble the mushroom in form and colour. If these characters are taken, with the general nature of the true habitat, viz., rich and airy pastures, little fear of error in determination need be apprehended. Edible mushrooms never, as a rule, grow in woods, never in wet meadows, never on rotten stumps and palings, and seldom on dung or under the shades of trees.

The structure of a mushroom is very simple, and it possesses none of the complicated parts found in some flowering plants, ferns, and mosses. A mushroom is wholly built up of cells or semi-transparent bladders of extreme minuteness. So small and light are these cells that it takes one and a half million of millions (billions) of them, with their contained water, to form every ounce of the mushroom's weight. Some of these minute bladders are sausage-shaped, others are round, whilst a third set, on and near the gills, ultimately get coloured and otherwise differentiated, till at last the dark-coloured spores (the minute reproductive bodies analogous with seeds) are produced. The stem of a mushroom is entirely composed of an infinite number of microscopic, sausage-shaped cells or bladders, placed end on end and slightly interlaced. As these bladders approach the cap, and especially as they approach the surface of the gills, they gradually get rounder and denser. Water is a large constituent in the mushroom: it forms ninety per cent. of the whole plant, and passing through the walls of the cells permeates the whole fungus. All the more interesting structural points in a mushroom are to be found in the cap, chiefly in and upon the gills. To make an examination of the minute structure of the mushroom, the first thing necessary is to cut off the stem, and then cut a slice off the edge of the mushroom, as seen at A, Fig. 3. When this small slice is

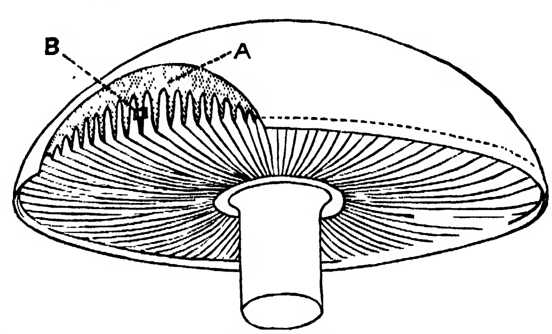

Fig. 3.—Section removed from edge of Cap of Edible Mushroom preparatory to minute examination.

removed, the gills will be seen cut across as in the diagram, and the gills now seen in section will resemble a number of teeth naturally outlined with a dark line, as shown. This dark line is a section of the *hymenium*, or fruiting surface, and this surface is studded all over with

the seeds or spores destined (under favourable circumstances) to reproduce the species. The hymenial surface or layer covers and follows all the folds of the gills, and it can in some fungi be peeled off and laid out flat like a handkerchief, or be floated in water as one continuous film. It may be compared in some fungi with the external layer on the convolutions of the brain of animals. A pocket lens, or even a low power of the microscope will show us little or nothing of the minute parts of a mushroom. To see even the constituent cells we must begin with a power of about 120 diameters. Our object now is to understand the structure of the gills in mushrooms, as seen in the section exposed at A, Fig. 3. For this purpose we must slice off an extremely thin and transparent fragment, such as might be enclosed in the very small square at B, Fig. 3. It should be said here that this square is represented at least ten times as large as the square the gills would naturally present. The drawing at Fig. 3 is a diagram, and necessarily conventional. The gills in nature are really as thin as sheets of writing-paper, and the atom to be seen in section would only well cover the point of a pin. When we get this transparent slice from the exposed surface of one of the gills, place it on clean glass, and magnify it 120 diameters, we see it as in Fig. 4. We here perceive the minute

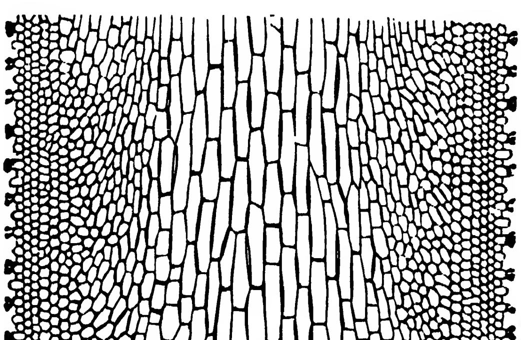

Fig. 4.—Transverse Section through fragment of Gill of Edible Mushroom, showing cell structure. (*Enlarged 120 diameters.*)

constituent cells or bladders quite distinctly. The longer and looser ones running down the middle (A A) belong to the *trama*, tramway or passage down the middle and between the two sides of the gills. The rounder and more compact cells at each side of the figure (B B) are the slightly-tinted cells of the hymenium or spore-bearing surface. The minute hollow dots running up the extreme edges on both sides are the spores. In some black-spored agarics the spores are so large that they can be clearly seen with a Coddington lens, but in the pasture mushroom they are so small that a power of one hundred and twenty diameters is perfectly useless for making

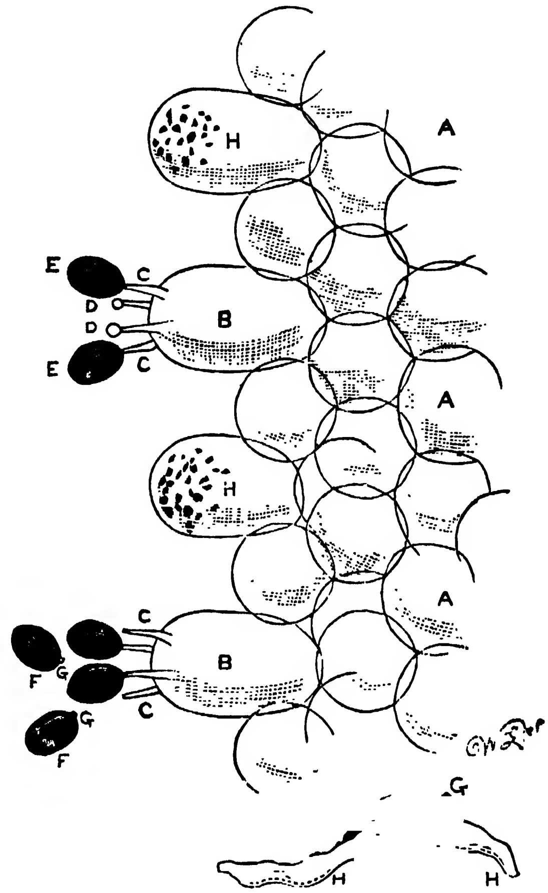

Fig. 5.—Section through Surface Cells of Gill of Edible Mushroom, showing Spores, &c., enlarged 1,500 diameters. Germinating Spore at foot enlarged 3,000 diameters.

them out. Fig. 5 shows us what can be seen with a magnifying power of one thousand five hundred diameters. It is needful for us now to direct our attention to the very edge of the section only, so that we may understand the nature of the hymenial surface. The cells at and about A A A, Fig. 5, are the ordinary cells or bladders of which the plant is built up; but as these cells approach the surface at the left edge they become "differentiated" (as botanists say), or become possessed of peculiar properties not possessed by the ordinary cells of the plant. The more important of the hymenial cells are shown at B B. These bladders are termed basidia, sporophores, or spore carriers. At first they resemble the ordinary cells, but they speedily become furnished with four small horns (C C C C), spicules, or "sterigmata." These horns bud at the point (D D), and the buds speedily grow into spores

(E E). The spores are at first white, then rose-colour, at length almost black. Two spores appear at a time diagonally on the spicules of the basidia, and as the two other spores on the remaining spicules quickly appear, they push off the two that were first formed in the manner shown at F F. Each spore is furnished with a minute projection at its base, answering to an umbilicus. This projection indicates the point of attachment to the mother mushroom. We may pause here for an instant to say that when, a few years ago, the great controversy was going on about "spontaneous generation," one of the leaders of the movement illustrated a spontaneously-generated spore. The spore was illustrated with a projection of this nature, plainly showing (by the umbilical spot) that it must have fallen from a true mother fungus. The sporophore, or spore-carrier, is clearly analogous to a female organism, but the presence or not of a male organism in the mushroom is much disputed. Many botanists, including the writer, believe male organs to be present in the cells, H H, named cysts, or cystidia. These cystidia are present (though often obscure) in all mushroom-like fungi; they are abundant on the hymenial surface, though less in number than the spore-carriers. The basidia, or spore-carriers, are about equal in number with the simple cells that are exposed on the hymenial surface. The cystidia are about one-quarter the number of the basidia; they are filled with protoplasm, and carry excessively minute granules in suspension. In some species there is a cover, which at a certain period of the growth of this fungus, flies off the cyst, and the minute granules sail out. Some botanists look upon these granules as analogous with the pollen in flowering plants, and the antherozoids of algæ, mosses, and ferns. Returning to the spores, they are each furnished with a distinct coat, which is at first white, becoming rose-colour, at length (from oxidisation) purplish-black. They are filled with condensed protoplasm, and are destined (after the manner of seeds) to reproduce the parent plant. When ripe, they drop away, or are pushed off from the hymenium, and if they fall in any suitable place they speedily burst. The bursting commonly takes place at both ends (H H), and the contained vital fluid, or protoplasm, pours out in the form of a fine thread. The spores burst readily enough on glass, damp linen, paper, and on various other materials in moist air. In a ripe mushroom, the spores of course fall from the hymenium to the earth in tens of thousands, and if the ground is suitably damp, and the air warm and moist, tens of thousands of fine mushroom threads will be produced on and in the ground, and this thready interlaced material, when incorporated with old dung and earth, is the "mushroom-spawn" of the mushroom-grower. A good way to see mushroom spores is to cut the stem off a mushroom close to the cap, and place the cap gills downwards on a sheet of white writing-paper or glass. If left all night in this position, a plentiful deposit of the spores will have fallen on to the paper or glass by the morning. In the mushroom the ripe spores are deep purplish-black or purplish-brown in colour, and this is one of the essential characters of the plant. Spores are short-lived, and when shed in an unsuitable place speedily perish: they cannot withstand any extremes of heat, dryness, or moisture. Not so the spawn; this, when once formed, can remain in a quiescent or resting condition for several years, though a superabundance of humidity or drought will, no doubt, injure or at length destroy it. The spawn, like the fungus which arises from it, is wholly cellular, and it carries the growth of fungi on from year to year in the same way as does the quiescent resting-spore of the fungus of the potato disease, described in Vol. III., p. 216.

Mushrooms are commonly looked upon as amongst the most rapid growing of all known plants; but this idea, correct on the whole, requires some little modification. It must be remembered that the ripe spores of the mushroom fall to the ground in October, and at that time burst and begin to form the perennial mycelium. The growth of this spawn or mycelium goes steadily on in the ground all through the winter, and all through the succeeding spring and summer. This spawn gradually gets denser and denser, and forms more and more cells whilst it is still hidden in the earth. When the autumn comes once again it is commonly forgotten that a whole year's subterranean growth of the mushroom has been going on unseen, and that bulb-like growths of the mushroom are present underground (like bulbs of lilies), ready to start into rapid growth on the advent of proper and favourable conditions. The warm and moist air of October is highly favourable for the development of mushrooms from the dense masses of living and mature subterranean fungus-spawn. From June to October mushroom "buttons," ranging from the size of a pin's point or head to that of a hazel-nut, may always be seen if the earth is turned over in mushroom-producing pastures. These buttons, if dissected, will be found to have all the parts of the

mushroom in a firm and consolidated state. The warm autumn rains soon distend the cells of the "buttons" to ten times their summer size, and then the young mushrooms peep out of the ground as white buttons the size of a large marble. The warm air of one or two days is sufficient for further growth, and the complete expansion of the umbrella-like cap. The supposition that mushrooms come up in a single night is founded on imperfect observation; the young plants are hidden by the grass and earth, and are overlooked. Experienced mycologists know perfectly well where the autumn agarics will appear even during the spring months: the condition of the pasture grass gives a clear indication. It is exactly the same with truffles: mycologists know at a glance, far better than any truffle dog, where truffles are certainly to be found; the neighbouring trees, the semi-open spots, the soil, calcareous or otherwise, give unerring indications.

Several fungi are frequently mistaken for true mushrooms by inexperienced persons, and the greatest stumbling-block is, no doubt, *Agaricus fastibilis*, Fr., and its close ally *A. crustuliniformis*, Bull. These two agarics generally grow in woods. They are clammy to the touch, have a very disagreeable smell, and the clay-brown but never black gills distinctly touch the ringless stem. The cap has no distinct hanging frill at the edge, and the spores or seeds are clay-brown in colour. These agarics look considerably like horse-mushrooms to an inexperienced observer, and they are sometimes seen exposed for sale with mushrooms in markets. They are highly poisonous. A trustworthy account has been published of the dangerous *A. fastibilis*, Fr., invading mushroom-beds and ousting the bed-mushrooms. Whether an incident of this class occurs rarely or frequently no one knows just now; but it clearly adds a serious difficulty to the correct determination of fungi, edible or otherwise, bought from dealers. Much more like a true mushroom is *A. cervinus*, Schæff., but this plant almost invariably grows on rotten stumps. The stem is perfectly ringless, and there is no hanging frill round the edge of cap. The gills are white, then permanently pink, never black. This is a suspicious species, belonging to a dangerous class. Not far removed from the true mushroom is *Agaricus velutinus*. This plant resembles a slender, thin-fleshed mushroom, with a hanging fringe round the edge of cap; and brown, at length black, gills, which in this species distinctly touch the ringless hollow stem.

220

It generally grows about rotten stumps, about dung, and in gardens. It is commonly exposed for sale with mushrooms, and like the next is largely used for ketchup-making. It, however, belongs to a suspicious cohort, and is probably dangerous. *A. lacrymabundus*, Bull., is frequently seen in mushroom-baskets. It is an ally of the last, but more like a mushroom. It grows in the same places with the last, and is as fleshy as a true mushroom. The gills, however, distinctly touch the hollow stem, and are generally studded with drops of moisture like tears, hence its name. This is, no doubt, a very doubtful if not dangerous plant.

The writer has investigated at different times many cases of poisoning from the consumption of "poisonous mushrooms," and in nearly every case the poisoning has arisen from fungi totally different in every respect from true mushrooms. One serious case was where a man had gathered a lot of scarlet-coloured fungi from a wood, and with his wife and family had consumed them for supper. The taste of the species (*Russula fragilis*, Fr.) is hot, like fire. Perhaps some of the pungency was dissipated in cooking, but a fiery-hot taste is often put down to "too much pepper." Another person gathered a basket full of semi-putrid fungi from rotten stumps, and cooked and consumed them, with unpleasant results. A third went into a London park, and gathered innumerable minute specimens from dung. When cooked this repast also had a disagreeable ending. A good test for an edible mushroom is its pleasant odour and its agreeable taste when raw, for most of the dangerous species are highly disagreeable to the nose and pungent to the palate when first gathered. Some act in another way, and cause speedy constriction of the throat. Cooking often causes the more serious poisonous properties to pass away from dangerous fungi: it must, however, be confessed that some of the most dangerous and insidious species are almost scentless and tasteless both when raw and cooked.

The symptoms of fungus poisoning are various. Effects similar to narcotic poisoning from laudanum, &c., are common. Giddiness, delirium, pains in the limbs are frequent, whilst at other times intestine irritation, excessive vomiting, and purging ensue. A few years ago the writer was called upon to identify some fungi which had nearly killed a Midland Railway engine-driver. The fungi were gathered at Hendon, and belonged to *Agaricus stercorarius*, Fr., an ally of the edible mushroom, but very much smaller in size, and always found growing on dung.

The engine-driver ate a pint of these things; in half an hour he had severe pains in the head, with giddiness and oppressed breathing. He soon began to stagger as if tipsy, and said he felt like "passing through an arcade." In three hours he became somewhat convulsed, with twitchings of the muscles of the face. At this period a strong mustard emetic was administered by a doctor without effect, and the doctor hastily left the patient to fetch some sulphate of zinc. The doctor had only left a few moments when the engine-driver became greatly excited, and rushed wildly out of the house into the street. Two doctors who followed found the poisoned man in a prostrate and lethargic state in a neighbour's house. Twenty grains of sulphate of zinc were now given, and this dose produced vomiting, and pieces of the poisonous fungi were brought up. Soon after the emetic the patient was again seized with sudden excitement, and he again rushed wildly into the street. Emetics were again administered, and the stomach was entirely cleared with the stomach-pump. In the course of a few hours, the patient recovered. He said he had experienced no pain in the stomach or bowels at any time, but when the convulsive paroxysms came on he felt an irresistible desire to run.

A bilious feeling and great nausea are common and early symptoms of fungus poisoning. In the absence of medical advice (or even with it) doses of sweet oil are an excellent palliative in mushroom poisoning. Repeated doses of oil are harmless: they almost invariably produce vomiting—which is, of course, what is primarily required—and have a tendency to lessen the irritation of the throat and intestines caused by noxious fungi.

ROCK-MAKING RHIZOPODS.

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THE Rhizopods, or root-footed animals, which are also known as the "ray-streamers," are some of the humblest members of the animal kingdom, forming an important subdivision of the great group of the *Protozoa*, or "first-life animals." This group, which occupies the very base of the animal scale, beneath the great sub-kingdoms marked out by Cuvier, is characterised by the extreme simplicity that prevails in the structure of the beings that it includes; for in the lowest of them there is scarcely any trace of what can properly be called organisation, while even in the highest, there is no such differentiation or appropriation of certain parts for particular functions as constitutes the "organs" of the very simplest zoophyte or worm.

The body of a Protozoan animal consists of one particle (or of several united together) of that living gelatinous material which is variously known as "sarcode," or "protoplasm." This substance, which we have already met with, possesses several fundamental vital properties, foremost among which is that of "contractility," viz., the power of changing its shape, owing to the influence of certain disturbing causes. These may arise spontaneously in consequence of internal changes in the protoplasm, about which we know little or nothing; or they may be due to changes in the surrounding circumstances of the protoplasmic particle, such as contact with a foreign body.

In its feeblest manifestations the contractility of animal protoplasm results in mere changes in the form of the body, as in *Gregarinæ* (p. 193); but from the sluggish shortenings and lengthenings of the different diameters of the body which these creatures exhibit, all gradations are traceable, through those animals which push out and retract broad lobular processes, to those in which the contractile prolongations take the form of long and slender filaments. These contractile prolongations sometimes perform rapid and rhythmical movements and vibrations in particular directions, and they are then called "cilia," or "flagella." The result of these vibrations is the locomotion of the tiny protoplasmic body which bears these organs. This is the case, for example, in the *Infusoria*, or Infusorial Animalcules,* a class of the Protozoa with which we are not now concerned; and we will, therefore, pass on to consider the Rhizopods. All the members of this class possess, in a greater or less degree, the power of putting forth indefinite extensions of the substance of the body which

* "Science for All," Vol. II., pp. 90, 206; Vol. IV., p. 114.

perform slow and irregular movements. They are sometimes short, broad, and rounded (Fig. 1); sometimes longer, more slender, and gradually tapering to a point; sometimes immensely elongated and narrowed to threads of extreme tenuity (Figs. 4, 5). They are perpetually varying in number, in form, and in dimensions, and can be withdrawn at any time, so as to melt away into the general protoplasm of the body, without leaving any trace of their previous existence. These diverging processes are known as *pseudopodia*,* for in some cases they serve to move the body from place to place in search of food, while they may also be used as prehensile organs for obtaining the food. As, therefore, they bear some resemblance both to the branching roots of a tree, and to the feet or locomotive appendages of the higher animals, the term *Rhizopoda*, or "root-footed," applied to the class of creatures of which their presence is so distinctive a characteristic, is by no means unexpressive.

The soft mass of protoplasm forming the essential part of the body of a Rhizopod has no internal cavity, like the body-cavity of the higher animals, or even like the digestive cavity of such a simple form as *Hydra*, for it has not even a permanent mouth, such as that which is present in the Infusorial Animalcules. Without any trace of a nervous apparatus, and almost entirely devoid of any internal organs at all, the Rhizopod—a mere jelly-speck—moves about with the apparent purposiveness which is exhibited by more complex creatures. It selects and swallows its appropriate food, digests it, and rejects its insoluble residue. It grows and reproduces its kind, and evolves a wonderful variety of different forms, which are often of the utmost beauty. All this results from the vital activity of its protoplasm, which performs all the different operations that are effected in the higher animals by a more or less elaborate apparatus. It is "a little particle of apparently homogeneous jelly, changing itself into a greater variety of forms than the fabled Proteus, laying hold of its food without members, swallowing it without a mouth, digesting it without a stomach, appropriating its nutritious material without absorbent vessels, or a circulating system, moving from place to place without muscles, feeling (if it has any power to do so) without nerves, propagating itself without genital apparatus; and not only this, but in many instances forming shelly coverings of a symmetry and complexity not surpassed by those of any testaceous animals."† The minute size of these marvellous little creatures is amply compensated by their multitude and their world-wide distribution. As pointed out by Professor Leidy—"Essentially aquatic, they occur wherever there is moisture. Commencing from one's own doorstep,‡ they may be found in almost every damp nook and crevice, savana and marsh, pool and ditch, pond and lake, sea and ocean, and from the greatest depths of the latter to the snow-line of mountains. By far the greater proportion are marine, and their tiny shells enter abundantly into the composition of the ocean mud, and abound in the sands of every ocean-shore. They appear to have been the first representatives of animal life on earth, and if there is any truth in the theory of evolution, they represent our own remotest ancestors. Having existed for ages, their remains have largely contributed to the formation of the marine sedimentary rocks."

No example of the Rhizopod type is more common in streams, ponds, and ditches, than the well-known *Amœba*, or Proteus-animalcule (Fig. 1),

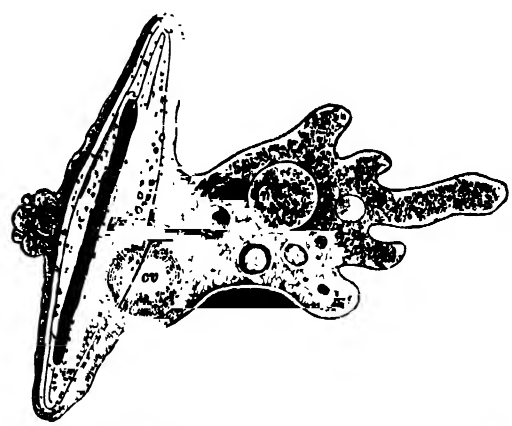

Fig. 1.—The Proteus-animalcule (*Amœba*), showing its Nucleus (*n*) and Contractile Vesicle (*cv*). One end of the body is distended by a large diatom.

which was first described in the year 1755, in a German book entitled, "Recreations among Insects." Although already noticed,§ it deserves, in connection with our subject, a fuller description. It may reach $\frac{1}{80}''$ in size, and has an irregular body of ever-changing shape. The outer layer of its protoplasm is somewhat different from the more internal portion. It is rather firmer and more

* Greek *pseudos*, false, and *pous*, a foot.

† W. B. Carpenter: Introduction to the Study of the *Foraminifera*, Preface, p. vii.

‡ Professor Leidy discovered a new species of *Gromia* ("Science for All," Vol. V., p. 191), together with several other microscopic animals, among moss growing in the crevices of the pavement in the yard attached to his house.

§ "Science for All," Vol. I., p. 176; Vol. IV., p. 112.

transparent, and though actually continuous with the interior, more fluid protoplasm, seems like an investing membrane which prevents its escape. For the sake of convenience of reference, these two portions of protoplasm, differently related in position, are known as the *endosarc* and the *ectosarc* —*i.e.*, the inner and the outer flesh. The former contains coloured granules of all sizes, from those which are immeasurably fine and indistinct up to the largest granules, which are more or less darkly defined, and resemble oil molecules. These move freely upon one another with every change in the shape of the body. The formation of a pseudopod commences as a projection of the clear ectosarc, into which, if the pseudopod is to be a large one, the endosarc flows, often with a sudden rush. An active current of granules may be seen to pass from what was previously the centre of the body into the protruded portion, where the latter is undergoing rapid elongation; whilst a like current may set towards the centre of the body from some other protrusion which is being withdrawn into it. It is in this manner that an *Amœba* moves from place to place, a protrusion like the finger of a glove being first formed, into which the substance of the body itself is gradually transferred, and another protrusion being put forth, either in the same or in some different direction, so soon as this transference has been accomplished, or even before it is complete. The changes of form produced by the extension and branching of certain of the pseudopods, with the recession, melting away, and total disappearance of others, are endless. Sometimes the animal creeps onward, in a flowing manner, with a comparatively simple cylindroid form, occasionally emitting a single pseudopod on one side or the other. More commonly, it assumes a dendroid or palmate form, or sometimes diverging from the directly onward course, it becomes more radiate in appearance. Not unfrequently, it assumes more or less grotesque shapes, in which almost every conceivable likeness may be imagined. It is in the course of this movement from place to place that the *Amœba* encounters particles which are fitted to afford it nourishment; and it appears to receive such particles into its interior through any part of the ectosarc, whether of the body itself or of any of its lobose expansions, insoluble particles which resist the digestive process being got rid of in the like primitive fashion. These particles pass through the ectosarc much in the same way as a knife-blade passes through a soap-bubble, the rent formed by their passage being immediately repaired by the closing up of the ectosarc behind them. The food particles usually appear in the endosarc as spherical balls, each with a clear halo around it. This indicates the presence of tiny water-drops, which had been swallowed at the same time as the solid particles, and had surrounded them. Sometimes the food-balls exhibit no vestige of such a halo, in which case we may assume that the water which had been swallowed with the food, and had surrounded the ball, has been gradually imbibed by the enclosing endosarc. Sometimes, also, the endosarc contains the indigestible remains of desmids and diatoms (Fig. 1), or even bodies of an entirely foreign nature.

Thus, Prof. Leidy records that in some fine, large, vigorous *Amœbæ* which were collected from a pond in the neighbourhood of a saw-mill, the endosarc contained multitudes of particles of sawdust; and other observers have succeeded in inducing *Amœbæ* to take in particles of indigo or carmine, which have been visible within the endosarc as tiny blue or red specks.

The endosarc of a true *Amœba* contains two structures or organs, which are known, respectively, as the "nucleus" and "the contractile vesicle." The former (Fig. 1, *n*) is usually a rounded or oval body, somewhat denser than the protoplasm in which it is imbedded, and slightly different from it in its optical and chemical characters. Its real nature is not yet thoroughly understood. The name of contractile vesicles is given to spaces in the protoplasm (Fig. 1, *c v*), which slowly become filled with a clear watery fluid, and when they have reached a certain size are suddenly obliterated by the coming together on all sides of the protoplasm in which they lie. After the collapse the space disappears for the moment, usually re-appearing again in the same position, and the successive movements of expansion and collapse follow one another with a certain degree of regularity. There is much reason to think that the vesicle communicates with the exterior, and that its movements are due to a gradual concentration of water from all parts of the protoplasm of the body, so as to form a drop which, when it reaches a certain size, excites contraction, and is expelled. It is probable that this apparatus has something to do with the work of breathing, and the removal of waste products from the body.

There are many other fresh-water Rhizopods which are naked like the *Amœba*, and have no real distinction in the relative positions of their parts, putting forth pseudopods indifferently from any part of the body. But many kinds are provided with an external shell or "test," which usually has

somewhat the shape of a flask or vase. Except in a few cases, the shell has but one opening—the mouth—from which the pseudopods are extended. It is either horny or flinty in character, or it is constructed of minute particles of sand closely cemented together. But so far as is known no fresh-water Rhizopod has a limestone shell. The marine forms, however, build shells which usually consist of limestone, sometimes more or less en-

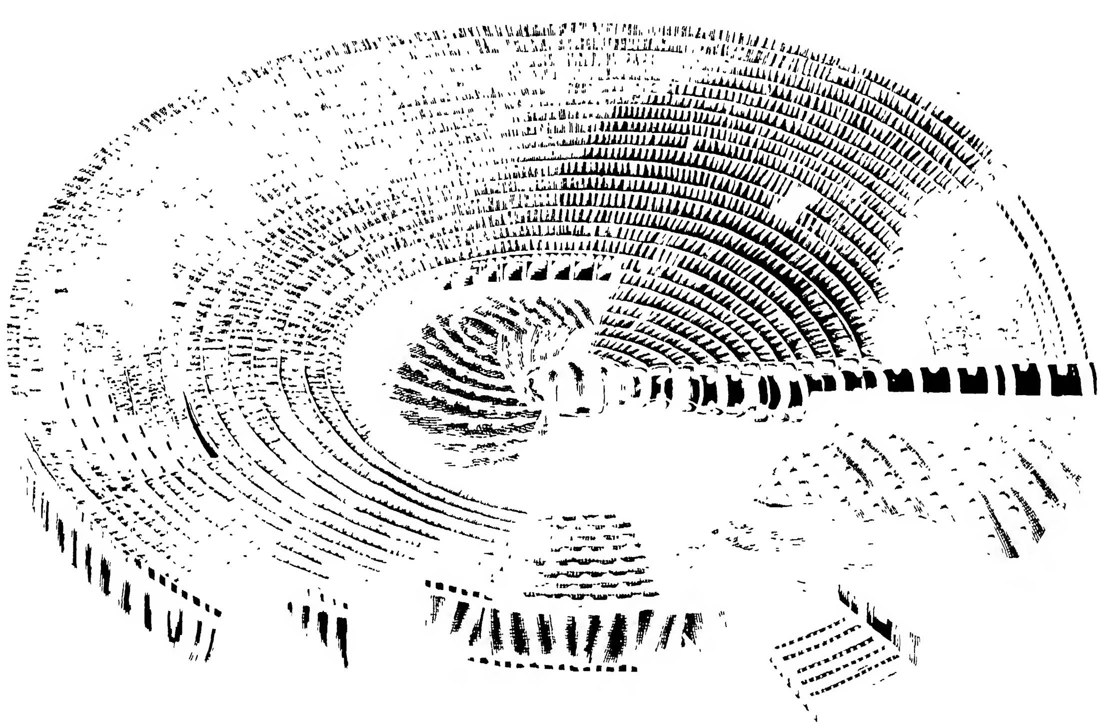

Fig. 2.—Shell of Orbitolites, Portions of which have been Removed so as to Expose the Individual Chambers, the Passages by which they Communicate with each other, and the External Openings of those in the Outer Ring.

crusted with sand grains that are imbedded in the proper shell-substance, and in one section of the group the body is enclosed by a test which consists entirely of minute sand-grains held together by an organic glue.

With a few exceptions, these shells are divided into many chambers, and the most common forms, which are spiral, so nearly resemble the shells of the Nautilus and the Ammonite that they were formerly ranked together with these creatures, among the shell-fish in the class Cephalopoda. The enormous differences in the nature of the animals which inhabited the shells were for a long time quite unknown, and the microscopic forms were distinguished from the Nautilus and its allies, in which the chambers are connected by a tube or siphon (*Siphonifera*), by the designation *Foraminifera.** This name, while originally signifying that the communications between the chambers are usually effected by several small holes or foramina, is now more commonly understood as applying to the sieve-like structure often presented by the external shell.

The *Foraminifera* constitute by far the most important order of the Rhizopods. This is partly owing to the vast quantities of them which have existed throughout all geological periods, from the earliest known appearance of life upon the earth until the present time, and partly because of the enormous extent in which their remains have contributed to the formation of rocks. They are widely distributed through all seas, creeping about on the surface of sea-weeds, or of the sand, ooze, or rock at the bottom, or on dead shells and corals, or

* "Science for All," Vol. I., pp. 10, 14, 66; Vol. II., p. 277; Vol. III., pp. 79, 206; Vol. IV., p. 122; Vol. V., p. 65, &c.

on the lifeless, fixed, hard parts of other living animals, such as the shells of mollusks, corals, sertularians,* and sponges. Large numbers are pelagic, or live on the high seas, swimming in the superficial water, while their dead shells rain down incessantly upon the bottom, and contribute largely to the formation of the deep-sea ooze.†

Although the Foraminifera are generally so minute as not to be readily distinguished by the naked eye, they are easily detected by a simple magnifying glass. They are usually largest in tropical seas, the same species being better developed in warmer than in colder latitudes. Few of the existing ones are more than an inch in length, while the fossil discs of Nummulites may attain the gigantic size of 4½ inches across, and the sandy test of *Parkeria*, from the Cambridge Greensand, may be about the size of a lawn tennis ball.

Dead Foraminiferal shells are usually very important constituents of shore-sands, particularly in warm climates. A grain of sand from the coast of Sicily has been estimated to contain 6,500 individuals, and an ounce of sand from the coast of New Jersey was calculated by Professor Leidy to contain 38,400 shells, all of the same kind.

The test of a fresh-water Rhizopod contains but a single *Amœba*-like individual, and the same is the case in some of the marine forms with limestone shells, which are spherical or flask-shaped, with a single opening from which the pseudopods are protruded; but by far the greater number of Foraminiferal shells are composite fabrics, which are produced by a process of continuous budding, each bud remaining in connection with the body by which it was put forth. The appearance of the structure thus formed depends upon the plan according to which the budding takes place. A large Foraminifer is a colony of *Amœba*-like animals gradually developed by continued budding from a single individual, just in the same way as a sea-fir is a colony of *Hydra*-like animals produced by a process of continuous budding from a primitively single being that has itself developed from a free-swimming ciliated egg.‡

Each bud of a Foraminifer surrounds itself with a shelly covering, the substance of which is continuous with that of the previously formed buds, and this results in the production of a many-chambered shell, the chambers communicating with one another by the openings which originally constituted their mouths. The successive chambers may be irregularly heaped together, or added one after another in a straight line, or in spirals of various shapes.§ In one form of spiral the successive whorls all lie in one plane, so that the shell is equilateral, or similar on its two sides. This arrangement passes gradually into what is known as the cyclical mode of growth, in which the parent individual develops buds all round, and not on one side only, so that a ring of small chambers is formed around the original one, and this, in its turn, surrounds itself in the same manner with another ring. By successive repetitions of this process, the shell comes to have the form of a disc made up of a great number of concentric rings (Fig. 2). Each ring is composed of a number of tiny chambers placed side by side, and communicating with one another by lateral passages, so that each circular zone of chambers might be described as a continuous annular passage dilated into cavities at intervals.

Every chamber contains a little segment of protoplasm, which is united to its neighbours by tiny threads or "stolons" of the same substance, that occupy the lateral passages between the chambers. The microscopic characters of the protoplasmic segments within the larger Foraminiferal shells have not yet been investigated, but there is no reason to think that they differ in any respect from those of the smaller members of the group. Fig. 3 is a representation of the body of a young *Miliola*, consisting of four segments only, which are arranged in the form of an elongated spiral. They consist of coarsely granular protoplasm, each containing one or more nuclei of essentially the same nature as that in *Amœba*. The protoplasm is usually yellowish-brown or red, the colouring being deepest in the earlier-formed chambers of the shell, and becoming less towards the last one, in which it is very feeble, or absent altogether.

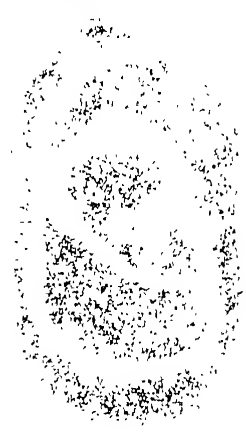

Fig. 3.—Protoplasmic body of a young *Miliola*, consisting of four nucleated segments.

In some Foraminifera which form spiral shells such as *Miliola* (Fig. 4), pseudopodia are only pro-

* "Science for All," Vol. I., p. 378; Vol. II., pp. 207, 312.
† "Science for All," Vol. III., pp. 79, 80.
‡ "Science for All," Vol. I., p. 378; Vol. II., pp. 207, 312—314; Vol. III., pp. 5, 187; Vol. IV., p. 156.
§ "Science for All," Vol. IV., p. 122, Figs. 4—7.

truded from the last-formed segment of the protoplasmic body, issuing from the mouth of the chamber which surrounds it, so that all the food materials of

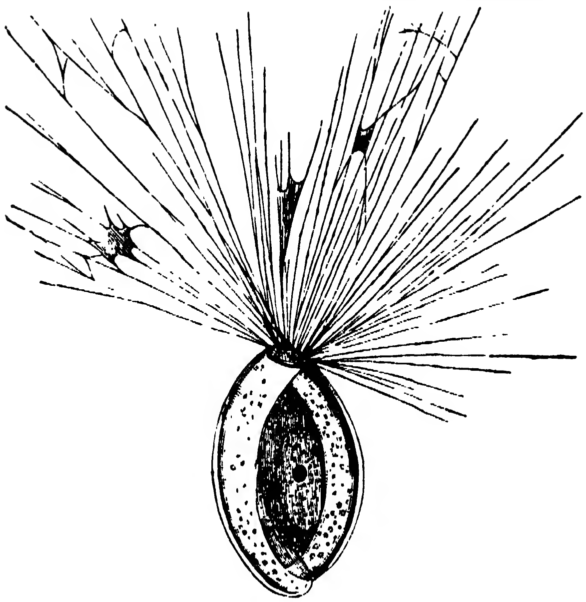

Fig. 4.—A living *Miliola*, one of the imperforate Foraminifera, with the Pseudopods extended from the mouth of the shell.

the body must be first received into its youngest and outermost segment, and thence transmitted from one segment to another until they reach the

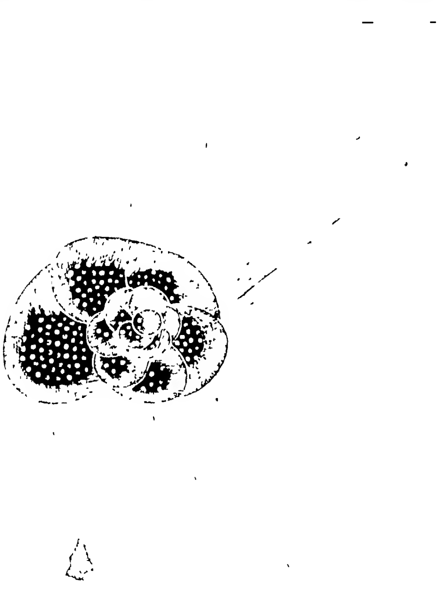

Fig. 5.—A living *Rotalia*, one of the perforate Foraminifera, with the Pseudopods extended through tubuli in the walls of the chambers.

oldest or first-formed one. Where the segments are arranged in successive rings, as in *Orbitolites* (Fig. 2), it is only those of the outermost and last-formed ring from which pseudopodia are protruded. But in other Foraminifera, such as *Globigerina*, *Nummulina*, and *Rotalia* (Fig. 5), the shell wall is everywhere pierced by very fine canals or tubuli, which pass directly from its inner to its outer surface (Figs. 6, 7). These give passage to the fine pseudopodia, which are extended from every segment of the protoplasmic body, and not from the last ones only. They pass at once into the surrounding medium, dividing and subdividing into

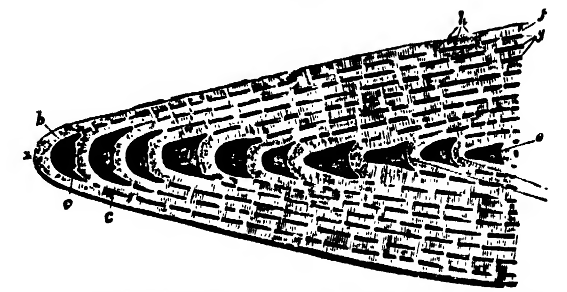

Fig. 6.—Vertical Section of the Shell of *Nummulites*, showing how its later whorls (*b*, *d*) overlap the earlier ones.

finer and finer threads, which coalesce completely when they come into contact, so as to produce an irregular protoplasmic network, that has been compared to an animated spider's web. They exhibit continual changes in their arrangement, and an incessant circulation in their course.* In the larger threads two streams may be seen at the same time moving in opposite directions, though in the finest threads there is but a single stream moving outwards or inwards. The currents carry along granules and oil-drops in the protoplasm, together with food particles, which may have been caught by the pseudopodia. The naturalists of the *Challenger* were fortunately enabled to watch this streaming movement of the protoplasm in the living *Globigerina*. When it was at rest, and uninjured, the protoplasm was seen to issue forth from the pores of the shell, and form a thin but continuous envelope around it. Extensions from this envelope clothed the spines, and were in a continual state of movement, the stream flowing up one side of each spine and down the other.

The perforations of the shell-wall for the exit of the pseudopodia are sometimes sufficiently coarse for their openings to be distinguished as punctures of the surface of the shell (Fig. 5). But in other cases the tubules are much more minute, parallel, and very closely set, so as to be only visible when thin sections of the shell-wall

* "Science for All," Vol. I., pp. 176, 295, 378; Vol. III., p. 80; Vol. IV., p. 110.

are examined in the microscope. This is well seen in vertical sections of the thick shells of the largest members of the group, such as the Nummulites

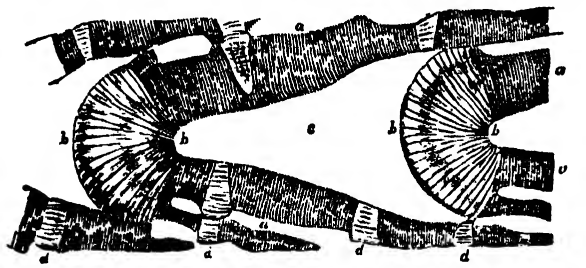

Fig. 7.—Portion of a Vertical Section of the Shell of *Nummulites* (highly magnified) to show the minute structure of the shell.
a, a, Portions of the ordinary shell-substance traversed by parallel tubuli; *b b*, portions forming the marginal cord of each whorl, traversed by diverging and larger tubuli; *c*, one of the chambers laid open; *d d*, pillars of solid shell substance, not perforated by tubuli.

(Figs. 6 and 7). The presence or absence of these tubuli, whatever their size, indicates a very important physiological difference between the animal inhabitants of the two kinds of shell, *viz.*, the mode of nutrition, as was pointed out above.

Whether the shell be perforate or imperforate, however, it may attain a very considerable degree of complexity, according to the number and arrangement of its chambers. In many Orbitolites, for example (Fig. 2), the disc contains three tiers of chambers instead of one, as in the simplest type. The chambers of the middle tier are the largest, and there are smaller ones above and below them. The outer ring of chambers in each tier communicates with the exterior by marginal pores, and all the chambers are connected together by a very complicated series of passages, though their general arrangement is essentially the same as in the simpler type, in which all the members of the colony are in the same plane.

Among the perforate Foraminifera we meet with more complicated organisations than among the imperforate forms. Whether the mode of growth be cyclical or spiral, the new chambers may extend themselves more or less completely over those already formed, and instead of the two series fitting closely to one another as they do in *Miliola* (Figs. 3, 4), interspaces are left between the successive rings or whorls. These become filled up by an intermediate skeleton of limestone, which is pierced by canals containing extensions of the protoplasmic bodies within the chambers. This is well shown in Fig. 8, which represents an internal cast of the shell of an Australian Foraminifer, the body of which has been entirely replaced by mineral matter. The individual segments, which have smooth anterior edges (b, b'), but are produced backwards into a series of processes (a, a'), are seen to be connected with one another by stolons (c, c'). The upper and the lower ends, respectively, of all the segments, are connected by spiral canals (d, d^1, and d^2). These are themselves united by a set of meridional canals (e, e^1, e^2), which pass down in the partitions between the chambers and give off pairs of diverging branches (f, f^1, f^2) that open into furrows on the external walls of the chambers. All these canals were occupied by protoplasmic threads, the casts of which are shown in Fig. 8. As the shell grew, and each whorl of segments became enclosed by another and larger one, the diverging stolons occupying the branches of its meridional canals united with the stolons connecting the successive segments of the outer whorl as is shown at c'. By means of this canal system, therefore, a very complete system of intercommunication is

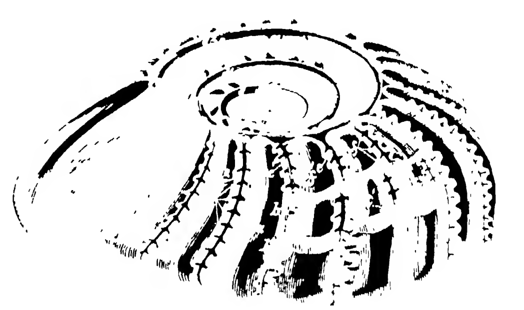

Fig. 8.—Internal Cast of Shell of Polystomella.

maintained between the external surface and the innermost portions of the shell.

All the most elaborately-constructed, and the greater part of the largest of the perforate Foraminifera, belong to a group of which the well-known Nummulite* may be taken as the representative.

Among all the different kinds of Foraminifera there is none which has either so long or so generally attracted the attention of naturalists as that which, owing to its coin-like appearance, is now familiarly known under the designation *Nummulites*. This is due, partly to the comparatively gigantic size (4½ inches) which it may attain, and partly to the manner in which it is brought to our notice. Enormous aggregations of Nummulites, together with some intermixture of other types of animal life, constitute a stratum of limestone, which not unfrequently attains a thickness of 1,500 feet, and is found over a very large area of the surface of

* "Science for All," Vol. IV., p. 123, Fig. 9.

our globe. It enters into the composition of many mountain chains, such as the Alps, Pyrenees, Appenines, Carpathians, and Caucasus, reaching, in the first-named, to a height of 10,000 feet. It covers large areas in Northern Africa, extending from Morocco into Algeria, Libya, and Egypt, and through Asia Minor, across Persia, by Bagdad, to the mouths of the Indus. It enters into the mountain ranges which separate Scinde from Persia, and is found at a height of 16,500 feet in the mountains of Western Tibet. It occurs in Afghanistan in the passes leading to Cabul, and extends along the southern slopes of the Himalayas, across India to Eastern Bengal and the frontiers of China. Every one of the Nummulites composing it lived and died on the ocean-bed ages before any of the mountain ranges above-mentioned were carved out of the newly-elevated continents by the process of earth-sculpture.

The limestone beds belong to the early part of the Tertiary period of geological time, and correspond in position with the "Calcaire grossier" of the Paris basin, and with the "Bracklesham" and "Bagshot" beds of the London and Hampshire basins, in which deposits alone are Nummulites found in the British Islands. They also occur in Japan, Java, and the Philippine Islands, and in the lower Tertiary beds of South Carolina in the United States. Living Nummulites are not very common, and are all of small size as compared with their predecessors of the Eocene Seas. Those of our own coasts do not exceed one-twelfth of an inch in diameter; and specimens from the tropics are rarely more than a quarter of an inch wide; while the fossil ones are usually three or four times as large as this.

It is of the Nummulitic limestone that the pyramids are partly built; and it is in relation to those structures that we find the first recorded mention of Nummulites. They were supposed to be the petrified remains of the lentils employed by the workmen as food; but Strabo remarked that this was not probable, as a hill in Pontus consisted of stone which was filled with similar lentil-like bodies. In Transylvania they were long supposed to be pieces of money turned into stone by king Ladislaus, in order to prevent his soldiers from stopping to collect them just when they were putting the Tartars to flight.

Even among the naturalists of the eighteenth century a great variety of notions prevailed as to the essential character of these fossils. Some regarded them as a new kind of "Cornu Ammonis;" others took them for the madreporic plates of sea-urchins; others maintained that they were bivalve shell-fish; while even Cuvier and Lamarck considered them as closely allied to the nautilus. Their general structure will be readily understood from a comparison of the vertical section shown in Fig. 6, with the horizontal sections shown in Fig. 9, on p. 123, Vol. IV., of this work.

The shell is really a spiral one, but the later whorls overlap the earlier ones, and invest them so completely that the spire is scarcely visible on the external surface. The perforation of the chamber-walls, however, by fine parallel tubuli (Fig. 7) which lodge pseudopodial extensions of the protoplasmic segments, indicates that even the oldest and innermost chambers retain their original communication with the exterior.

Among the commonest of all Foraminifera, and abounding near the shores of almost every sea, are some forms of the Milioline type (Fig. 4), which was so named in consequence of the resemblance of some of the minute fossil shells to millet seeds. These Miliola-shells form the chief part of certain beds in the "Calcaire grossier," already mentioned as a coarse limestone of Tertiary age in the neighbourhood of Paris. This rock is known, in consequence, as the "Miliolite limestone;" and as it is largely employed for building purposes it was pointed out by D'Orbigny some years ago that it would be no exaggeration to say that Paris, as well as the towns and villages of some of the surrounding departments, are almost built of Foraminifera.

It has already been explained that large areas of the bottom of the Atlantic, and of the Southern and middle Pacific Oceans are being covered by foraminiferal shells, which have been rained down upon them from the surface of the sea. A foraminiferal limestone is now being formed in these localities, just as the white chalk, which we all know so well, was once formed at the bottom of a sea that spread not only over the greater part of Britain, but also over a very large part of the Europe of the present day, long before the Alps and the Pyrenees rose into mountain chains, and only a few islands formed of Palæozoic rocks stood above the waves. Pure chalk, of nearly uniform aspect and composition, is met with in a north-west and south-east direction, from the north of Ireland to the Crimea, a distance of 1,140 geographical miles; and in the direction across this it extends from the south of Sweden into south-western France, a distance of about 840 geographical miles.

It is well-known to the reader of these pages

that chalk is nothing but a soft limestone,* which is chiefly composed of foraminiferal shells. This was discovered by Professor Ehrenberg of Berlin, and during the course of his researches it occurred to him to examine the finer particles of calcareous matter which have been artificially separated from chalk, and are employed for various purposes. The glazing of the papers used on our walls, and that of visiting-cards, is partly composed of this material; and on scraping a little of it, and subjecting it to microscopic examination, Ehrenberg was delighted to find its organic structure almost everywhere apparent.

The cretaceous period in America, as in Europe, is marked by a limestone formation. The great interior continental basin, which had been a limestone-making region (for the most part) from the earliest period of the Silurian, was still, in its southern part—that is in Texas—continuing the same work; for limestones eight hundred feet thick were there formed, chiefly from the remains of echinoderms, corals, and a foraminifer known as *Orbitolina Texana* (Fig. 9), which is so abundant in some beds that they may almost be called foraminiferal limestones. During the Carboniferous period when limestones were being formed, both in America and in Europe, Foraminifera took a large share of the work. One form, known as *Fusulina* (Fig. 10), which is particularly abundant in some beds, has a shell that is almost the size and shape of a grain of wheat. It is especially interesting, as being exclusively a Carboniferous type, though very widely distributed. It is common in the limestone beds of Russia, the Southern Alps, Armenia, and Spain, and has an extensive distribution through the Carboniferous series of North America, being found as far north as Melville Island—so well-known to the readers of Arctic travels.

Fig. 9.—Orbitolina Texana.

Fig. 10.—Fusulina Limestone.

The foraminiferal origin of our mountain limestone is excellently illustrated in a case described by Professor Williamson. A slab of the rock from Bolland, when sawn through, was found to contain a large Nautilus-shell more than twelve inches in diameter. The matrix in which it was imbedded had once been foraminiferal ooze, but the individual shells were so worn as to be hardly distinguishable. Professor Williamson attributes this wearing down of the shells to the solvent action of water containing carbonic acid, a conclusion which is well supported by the state of the contents of the chambers of the Nautilus-shell. The foraminiferal ooze has entered freely through the large open mouth of the terminal chamber in which the animal lived, and has filled the entire cavity of that chamber. The shells composing it are not, however, worn and indistinct like those of the surrounding matrix, but almost every one is preserved in the most exquisite perfection. The reason of this is, that the thick calcareous shell of the Nautilus has protected the enclosed foraminiferal shells from the action of the solvent acid. The *closed* inner chambers of the Nautilus-shell are all filled with clear crystalline calcareous spar, which has been produced in the following manner. The acidulated water acting upon the calcareous Foraminifera of the ooze has become converted into a more or less saturated solution of carbonate of lime. This has percolated through the shell of the Nautilus into its hollow internal chambers. Finding suitable cavities there, it has gradually filled them up with a crystalline formation of calcareous spar, that of course exhibits no traces of the minute organisms from which the calcareous matter was primarily derived.

Here, therefore, we have the entire history of the origin and formation of a limestone rock, illustrated within the area of a slab of limestone little more than a foot in diameter. It commences with the first accumulation of the foraminiferal ooze, as seen in the interior of the first large chamber of the Nautilus, and ends with the deposition in an inorganic mineral form of the crystallised carbonate of lime within the closed chamber of the same shell.

Not only are many of our limestone rocks composed in greater or less part of foraminiferal shells, but many so-called "sands" have the same origin. The Green-sand bed on which the chalk rests, and other Green-sands belonging to still older geological periods, even as far back as the Silurian, are composed of minute particles of a greenish mineral that contains large quantities of silica, and goes by the general name of "glauconite." Many years ago it was pointed out by Professor Ehrenberg that these particles have definite shapes, which show them to be internal casts of foraminiferal shells, giving us the forms of the segments or divisions of the jelly-like animal body that occupied the chambers in its living state. Hence, while it is the life of Foraminifera, producing their lime-

* "Science for All," Vol. I., p. 14; III., p. 83; V., p. 65.

stone shells, which makes the chalk, it seems to be their death which gives rise to the casts.

Even at the present time similar internal casts of foraminiferal shells are being formed on the sea bottom in various parts of the world, *e.g.*, the Ægean Sea, the Agulhas Bank, the coast of Australia, and the Florida Straits. Some of the casts are much more perfect than any contained in the Green-sand. Not only the chambers, but the "canal system" proceeding from them, and even the minute tubuli in their walls are so completely filled with the green siliceous mineral, that by dissolving away the shell with dilute acid a most perfect model of the animal is obtained (Fig. 8).

This fact is of great importance in reference to the structure known as *Eozoon*,* which occurs in the Laurentian formation of Canada. Near the bottom of the series there is found a serpentine limestone, so called because it consists of alternate layers of carbonate of lime, and the mineral called serpentine, which is a silicate of magnesia. There is very strong reason to believe that many of the calcareous layers are really composed of a shelly substance, arranged in such a manner as to form storeys of chambers communicating with each other; that these chambers were occupied by an animal body extending into a canal system exactly comparable to that of recent Foraminifera; and that the serpentine has taken the place of this animal body, precisely as the glauconite has done in the case of the Green-sands mentioned above.

It is probable, therefore, that in the old Laurentian period *Eozoon* did the same work as was done by *Fusulina* in the Carboniferous seas, by *Nummulina* in the Eocene seas, and by *Globigerina* from the middle of the Cretaceous period until the present time. All these kinds of Foraminifera and many others, have produced great limestone-formations over extensive areas of the ocean-bed, by separating the carbonate of lime from its solution in sea-water, and making it take the solid form. In most Foraminifera the shell is limited in size, as the process of budding does not continue indefinitely. When a certain number of buds have been produced from the parent—about sixteen in *Globigerina* and considerably more in *Nummulina*—the next bud detaches itself, and begins to form a separate shell. But the growth of *Eozoon* was continuous and indefinite, like that of a vast tree. Each new bud, though capable of living independently, remained in connection with the organism that developed it, so as to produce a vast limestone formation, spreading like a coral reef over an immense area, though formed by animals of a much simpler kind than the coral polypes.

Lowly as is the rank of the Foraminifera in the scale of creation, the work which they have done since the first appearance of life upon this earth, which they are still doing, and will continue to do in future ages, is of an importance and extent that it is utterly impossible for us to realise. As has been well said by the illustrious Lamarck, "We scarcely condescend to examine microscopic shells from their insignificant size; but we cease to think them insignificant when we reflect that it is by the smallest objects that Nature everywhere produces her most remarkable and astonishing phenomena. Whatever she may seem to lose in point of volume in the production of living bodies, is amply made up by the number of the individuals, which multiply with admirable promptitude to infinity. The remains of such minute animals have added much more to the mass of materials, which compose the exterior crust of the globe than the bones of elephants, hippopotami, and whales."

THE DISTANT PLANETS—URANUS AND NEPTUNE.

By W. F. Denning, F.R.A.S.

The planet Saturn, situated at a mean distance of about 870,000,000 miles from the sun, was understood, during many ages, to be the outermost planet, which revolved on the very confines of the solar system, and included within its far-reaching orbit all the constituent members of that system. No other planet which, by its slow apparent movement and faint appearance, indicated a position exterior to that of Saturn had ever been discovered; indeed, only five planets were known, excluding the earth, and these were severally rendered conspicuous by their lustre, and by the fact of proper motion amongst the fixed stars. It had been suggested that other bodies might exist, but were probably invisible in consequence of their

* "Science for All," Vol. III., p. 206, Figs. 10—12.

vast distance from the earth, for no success had ever attended the efforts of those who had searched for such objects. With the invention of the telescope, at the beginning of the seventeenth century, and its subsequent employment in astronomical discoveries, some addition to the number of known planets might have been anticipated, but apart from the four satellites of Jupiter, and, later on, several of those attending Saturn, which were revealed by this new and valuable means of research, no fresh orbs were found, so that the position of Saturn as the farthermost planet remained quite undisturbed.

But towards the end of the eighteenth century, an observer, displaying the qualifications of an astronomer in an eminent degree, was destined to make a significant advance to the then state of knowledge, and to alter contemporary conceptions as to the range of the solar system. It was in 1781 that William Herschel, at Bath, while systematically reviewing the heavens with a reflecting telescope of his own construction, detected a strange body, which ultimately proved to be a major planet, revolving far outside the path of Saturn, at approximately double the distance. This discovery was soon supplemented by others of importance; astronomical instruments were much improved and enlarged, and the assiduity of observers increased. Thus, the century which has elapsed since the discovery of Uranus has been productive of great results in every department of the science. The epoch was specially marked by the detection (in 1846) of another superior planet, called Neptune, which displaced Uranus as the most distant planet, and whose discovery is rightly described as a very brilliant achievement of the human intellect. The existence of the new orb was, in fact, demonstrated before it had ever been seen, and its place in the firmament assigned, so that a telescope had simply to be turned towards the spot in order that the calculations might be verified. This was actually done on September 23, 1846. Two distinguished mathematicians, Le Verrier and Adams, divide the honour of this unique discovery. They had independently concluded that certain perturbations affecting Uranus, other than those due to the action of Jupiter and Saturn, must be referred to an unknown body situated outside Uranus; and the complex problem involved in the computation of the position of the new orb was attempted, and finally accomplished, with such unerring accuracy as to result in its actual discovery by Galle of Berlin.

We propose giving in the present paper some particulars both of Uranus and Neptune, for though such distant planets possess little of interest to ordinary observers, they, nevertheless, deserve prominent notice from those who would review the leading members of the solar system. That these orbs are apparently of the faintest character, and present no attractive features for observation, is due to the fact of their vast distance, which places such phenomena wholly beyond our reach. Possibly they may exhibit a remarkable variety of surface configuration, even comparable with that so readily distinguishable on Jupiter or Mars; but it is obvious that such details will never be defined accurately until telescopic power is greatly increased.

Uranus is well within reach of the naked eye, and its position can readily be found from an ephemeris.* If any doubt exists as to its identity, let the observer delineate the relative positions of the faint stars in the immediate vicinity, and make comparative observations a few nights afterwards, when the planet will be detected by its motion. A powerful glass will always reveal the planet's disc, and thus obviate the necessity of duplicate observations. The writer has frequently seen Uranus with the unaided eye, and traced its varying place with reference to adjoining stars. Indeed, it is rather curious that this planet escaped detection so long when we consider that its discovery was possible without instrumental means, by simply noting the exact positions of the fainter stars, and comparing them afterwards for such variation as a planetary body must necessarily soon exhibit. Had this method been adopted, there is no doubt that Herschel would have been anticipated in that great discovery which not only made him famous, but acted as an incentive on other observers to employ themselves with more assiduity in the exploration of the heavens.

When, on the night of March 13, 1781, the discovery was made, its true import was not imagined. It was announced as a singular comet, with a disc, lying between the stars of Taurus and Gemini. Moreover, its detection arose from accidental circumstances. Herschel happened to be examining with critical attention a region on the borders of Gemini, with the idea of finding double stars, nebulæ, or other objects of interest, but alighting upon the planet situated there, at once remarked its unique appearance relative to the

* An almanack, or astronomical table, giving the daily places of the sun, moon, and planets, and other celestial phenomena.

neighbouring stars. Applying increased power to his telescope, he noted that it presented a planetary disc, while the stars near retained their invariable aspect, and were visible, even when magnified to the fullest capacity of his telescope, as points of light. The strange object had fully excited his curiosity, so that he determined its place, and re-observed it on subsequent occasions, finding that it was in motion. A difficulty now arose as to its real character, and Herschel was led to assume that it must be a singular comet, and as such he described it.* It then became an object of general interest to astronomers, and was keenly watched. A parabolic orbit was calculated, fairly representing the observations which had been obtained, but it was soon found that this would not satisfy the motion of the new body. The position predicted from parabolic elements, such as are usually applicable to cometary orbits, was found in this case to be widely discordant with that observed; in fact, the path of the alleged comet could not be reconciled with theoretical deductions, and it had to be admitted that the case required re-investigation on the basis of the more extensive observations which in the meantime had accumulated. The truth could no longer be delayed. A nearly circular orbit was found to be the only one according with the motions of the strange body, and it was suggested that it could not be a comet, but a large planet exterior to Saturn. This view, though not received with universal favour at first, was soon adopted as the most satisfactory in its application, for every new observation tended to strengthen it, and the objections of sceptics soon disappeared.

The fact being acknowledged that the new body could be no other than a superior planet, it was suggested that, though not previously identified as such, it may possibly have been observed and mistaken for a fixed star by the authors of star catalogues, who could hardly have overlooked so conspicuous an object, for it was plainly within reach of the unaided eye. The places of the new planet were therefore roughly computed back, and a search instituted amongst observers' records, when it was soon found that it had been unmistakably detected on several occasions, and erroneously described as a star. This was rendered apparent by the fact that exactly in the spot occupied by the planet a fixed star had been inserted, where in each case none existed, but the observers had invariably failed to recognise the anomalous character of the object. This is, however, not surprising when we consider that a low power quite fails to reveal the disc of the planet, and that in the framing of star charts such a power is usually employed. But it seems remarkable that the motion of the planet always eluded detection, and that certain observers, who had become familiar by their frequent reviews with the configuration of the stars, should have again and again allowed it to escape identification. The old observations were, however, not without their purpose, for they enabled the orbit of the planet to be computed with more accuracy and facility than could otherwise have been the case (Fig. 1).

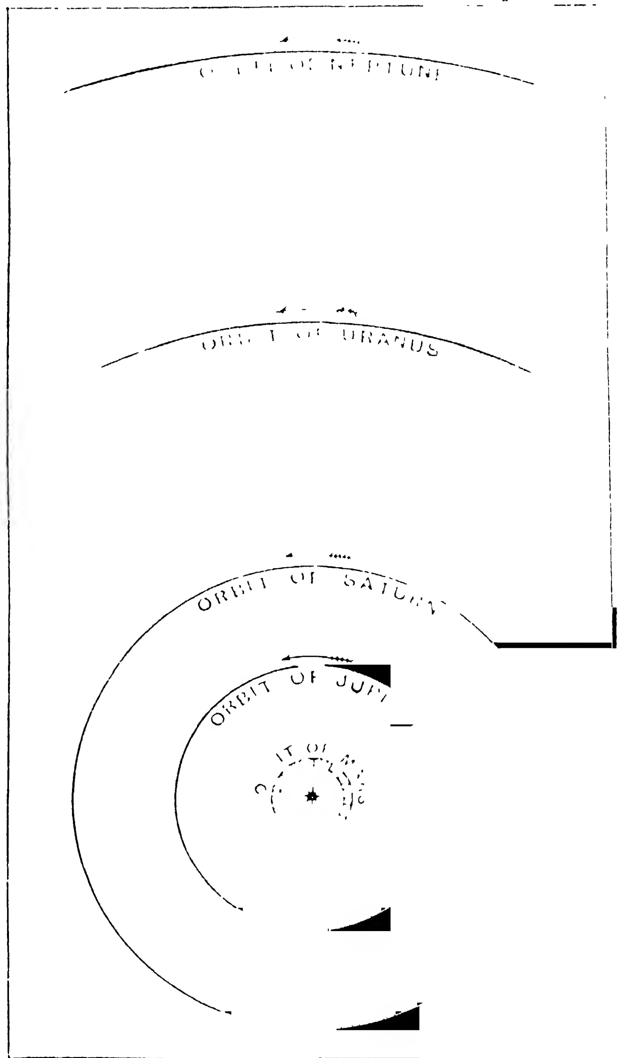

Fig. 1.—Relative Positions of the Orbits of the Earth and Exterior Planets.

It will be readily inferred that Uranus is not an object displaying any points of interest to ordinary telescopic observers. His vast distance and apparent minuteness obliterate whatever detail

* "Philosophical Transactions," 1781.

might, under more suitable conditions, have been revealed, so that we are wholly ignorant of the physical aspect of his surface. It is true that some glimpses of dusky belts and other markings have been obtained at various times, and the period of the planet's rotation has been uncertainly indicated, from their changing positions, as performed in about twelve hours; but the data are extremely slender, so that it would be unwise to give them full reliance. Such observations are evidently obtained with great difficulty and delicacy, and come only within the province of the best telescopes. And not only is the instrument required to be of the finest excellence, but the atmospheric conditions must be suitable to the work, for it is obviously useless to expect favourable results on a night when the air is unsteady, and its varying currents originate that undulating aspect which is ruinous to definition, and is so frequently the cause of annoyance to telescopic observers. A night of unusual excellence must be awaited, and then fully utilised, for in this climate we have so few thoroughly good opportunities that we cannot afford to let one pass disregarded.

Herschel was not slow to follow up his great discovery of a new planet. He at once commenced a rigorous search for its satellites, and on Jan. 11, 1787, discovered two, for which he computed periods of 8 days, 18 hours, and 13 days, 11 hours respectively. He continued, during subsequent years, to examine the region of the planet for suspected satellites, and ultimately became satisfied that he had discovered four others, making six in all, and numbered them progressively in the order of their distances from Uranus. Their periods of revolution were found to range between 5 days, 21 hours and 107 days, 16 hours; but the observation of these excessively minute points of light could only be attempted on rare occasions, so that the materials on which Herschel's results were based admitted of some doubt. Apart from the great feebleness of the supposed satellites, there was a difficulty of distinguishing them from small stars in the neighbourhood of the planet; in fact, it was often impossible to find, during the interval of an observation, whether any motion could be attributed to these faint objects. But the fact of at least six satellites surrounding Uranus was accepted on the testimony of so eminent an observer, and during the half-century that ensued little or no endeavour was made at corroboration, until Lassell attempted it in 1847, and succeeded in detecting two satellites, with periods differing from any of those assigned by Herschel. The two satellites seen in 1787 were re-discovered, but the additional four never gave the slightest clue to their existence; indeed, they have never been re-observed, and the inference is that they were merely faint stars situated near the planet. Uranus has therefore only four satellites of which we are certainly cognisant: namely, two found by Herschel in 1787, and two by Lassell in October, 1851, as follows:—

Order of Distance.	Name of Satellite.	Discoverer and Date.		Period of Satellite. d.	h.	m.	s.
I.	Ariel . . .	W. Lassell,	Oct. 24, 1851	2	12	29	20 7
II.	Umbriel . .	W. Lassell,	Oct. 24, 1851	4	3	23	7·5
III.	Titania . .	W. Herschel,	Jan. 11, 1787	8	16	56	25·6
IV.	Oberon . .	W. Herschel,	Jan. 11, 1787	13	11	6	55·4

The periods are those given by Lassell, whose instrumental means were superior to those of Herschel. Moreover, the observations of the former were made in the clear sky of Malta, while those of the latter were conducted in our own country, which is far less favourable in this respect. Considering, therefore, that Lassell with these advantages, and that other observers in late years have totally failed to glimpse more than two of the six satellites assumed to have been discovered by Herschel, we must conclude that they never existed. It is impossible to conceive that they could have eluded re-detection either by the large reflectors of Lassell or Lord Rosse, or by the great refractor of the Washington Observatory, which has fully proved its capacity for such work by the discovery of two satellites of Mars in August, 1877. We must, however, admit Uranus being accompanied by more than four satellites, if we found our ideas upon the analogies of the interior planets, which show that the number of satellites increases with greater distance from the sun, so that hereafter many additional ones may be discovered attending Uranus, several of which may reveal orbital resemblances to those assumed to exist by Herschel at the end of the last century. But should this ultimately prove to be the case, it will hardly be considered that they are identical, or that the original observations have been confirmed: unless, indeed, these bodies are liable to temporary obscurations, which is a theory that can scarcely be rendered tenable.

A singular circumstance in connection with the Uranian satellites is that their motions are *retrograde*, and that their orbital planes are nearly perpendicular to the ecliptic of the planet. This is in distinct contrast to what is exhibited by the

systems of Mars, Jupiter, and Saturn, whose satellites move in direct orbits, and without much deviation from the equatorial planes of their respective primaries.

The vast distance of Uranus, expressed by some 1,754,000,000 miles, though insignificant when compared with the enormous interval by which we are separated from the nearest fixed star, is yet beyond our conception, and the completion of a revolution round the sun must necessarily occupy the planet a very long period. No less than 30,687 of our days, or fully eighty-four years, are, in fact, expended in this single journey!

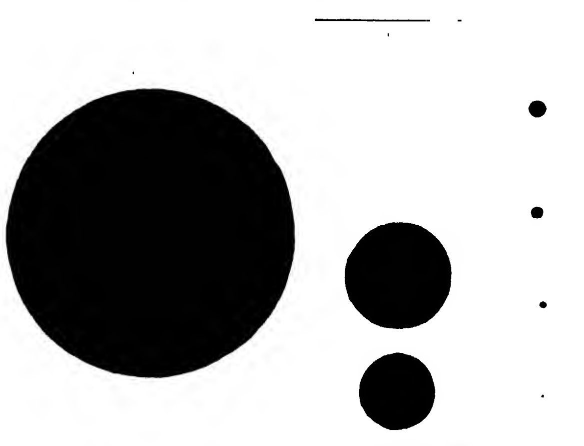

Fig. 2.—Apparent Dimensions of the Sun, as viewed from the several Planets.

It becomes obvious, in considering these questions, that the amount of sunlight received by the surface of Uranus must be extremely small. Situated as it is at such a remote distance from the centre of light and heat, we cannot help wondering, should the planet be inhabited, what animal life can be sustained under such adverse influences. The sun must necessarily appear with a comparatively minute disc (Fig. 2), wholly incapable of imparting life-giving elements, except in a very feeble measure; and it is evident that if this planet is the abode of animate creatures, they have to rely upon different circumstances from those which control life upon our own planet. But this is also true of each individual member of the planetary series, which, according to its distance from the sun, must have a special arrangement of surface phenomena; in fact, the orbits of the planets, being so vastly dissimilar as regards their solar distances, are liable to influences which destroy the analogy we might otherwise expect on their surfaces. We are here referring to the large planets of our system, and not to the numerous class of minor planets between Mars and Jupiter, many of which are situated at nearly equal distances from the sun, and are, therefore, all affected by circumstances of close affinity, so that the individual members may not present any anomalous details, but rather belong to a common order or family of bodies showing the same characteristic phenomena.

From the surface of Uranus it would be impossible to distinguish the intra-Jovian planets, Mercury, Venus, the Earth, and Mars, but Jupiter and Saturn would, no doubt, be distinguished, though with far less effect than from the earth. The sun would not offer much impediment to such observations, in consequence of his comparative feebleness. Neptune would be plainly distinguished, and possibly some more distant planets, of which we are now ignorant. The configuration of the stars would not be sensibly different, but the most attractive sight in the Uranian firmament must be the numerous satellites belonging to the planet, with their constantly changing positions and phases.

We have already referred to the discovery of Uranus as most important in its abstract sense, but it proved even more valuable in its bearings upon other questions, and the materials it directly furnished for another discovery, unique in itself, and significant as displaying the wonderful capacities of mathematical analysis, aided by human genius. We refer to the subsequent discovery of Neptune, the history of which has so often been written, so that we will content ourselves with a brief description of the leading facts.

In 1821 improved tables of Uranus were published by Bouvard, and by means of these it was thought the precise spot occupied by the planet at future epochs could be predicted with considerable certainty. It was, however, found that discrepancies arose, and that the motions of the planet did not exactly fulfil the required conditions. Yet every known element operating to disturb the orbit had been allowed for. The perturbations caused by Jupiter and Saturn were, no doubt, correctly represented, so that the somewhat erratic behaviour of the planet could not be readily explained, unless it was assumed to be brought about by the influence of a body, hitherto unknown, situated outside Uranus. This hypothesis was indeed suggested by Bouvard as the only convenient and feasible solution to the problem, for it soon became acknowledged that the motions of Uranus were in a measure affected by some agency which had been wholly neglected in the calculations (Fig. 3).

The theory of gravitation has taught us that an attractive influence is exercised by one body upon another, and that this varies according to the mass.

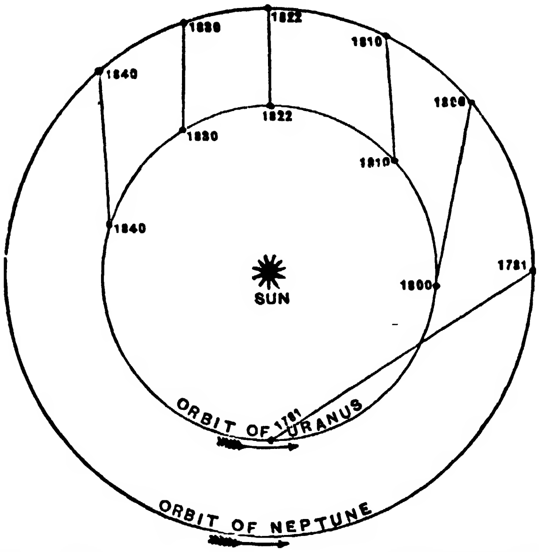

Fig. 3. —Diagram illustrating the Relative Positions of Uranus and Neptune from 1781 to 1840.

The effects of this attraction are to originate perturbations in the planetary motions, and they are of a complicated character, owing to the different magnitudes and distances of the bodies affected. Apart, therefore, from the main and central influence of the sun, the planets are subjected to certain extraneous forces originating amongst themselves, which give rise to slightly erratic movements, capable of being computed with remarkable precision. In Fig. 3 we have endeavoured to show the positions of Uranus and Neptune, and inspecting this, it will become apparent that between 1781 and 1822 the action of the (then unknown) planet Neptune was to draw Uranus in advance of the position calculated from independent sources. In 1822 the two planets arrived at conjunction, and no appreciable effects were manifest until some years later, when the motion of Uranus was in a measure retarded by Neptune.

Some years afterwards the subject was taken up practically by M. le Verrier in France, and by Mr. J. C. Adams in England. The new investigations appeared to corroborate the facts just recorded, and to indicate more distinctly than before the existence of a new and large planet revolving in an exterior orbit to Uranus. The important question to decide was the position of the unknown orb, and whether this could be computed with sufficient accuracy to render its detection probable. The work was attempted simultaneously by the two mathematicians named above, and by an elaborate process of investigation, involving many intricate and laborious details, the theoretical place of the suspected new body was found. It now became important that it should be searched for with adequate means, for, situated at so great a distance, it must essentially be visible only as an object of considerable faintness.

Professor Challis at the Cambridge Observatory, who had received an intimation from Mr. Adams as to the position of the new body, began in 1846 an assiduous scrutiny of the region in which it was presumably situated, and Dr. Galle of Berlin commenced a similar search. The planet was soon found. On September 23rd, 1846, Dr. Galle detected an object with a planetary disc close to the position assigned by Le Verrier, and motion afterwards became apparent, so that its real character was at once manifested. Professor Challis had also seen the planet on August 4th and 12th of the same year, but the priority of discovering it telescopically rests with Dr. Galle, who first actually identified it as the body sought for. Further observations only tended to render the facts conclusive, and to reveal the marvellous reach and accuracy of mathematical demonstration.

For some time the rival claims of Le Verrier and Adams were contested. Frenchmen objected that the latter ought to share equally with their own countryman the honour of the discovery. The part each had taken in the investigation was discussed, and it became evident that Mr. Adams must participate with Le Verrier in the credit attached to this astonishing discovery. The results of the latter had, it is true, proved slightly more accurate, for the heliocentric place of the planet upon its discovery was at 326° 52′, while Le Verrier gave it at 326° 0′, and Adams at 329° 19′; so that while the position given by Le Verrier differed from that observed by only 0° 52′, that of Adams was as much as 2° 27′ in error. But this cannot alter the fact that the difficult problem had been thoroughly worked out by both computers with eminently successful results, and that the honours of this brilliant performance should therefore be shared between them.

The question of an appropriate name for the planet came to the front immediately upon its discovery. Dr. Galle suggested "Janus" as a suitable title for the new body, but it was finally rejected in favour of "Neptune,"—a designation which soon became generally adopted.

Powerful telescopes were directed to the planet, with the idea of learning something of its physical aspect, but in the case of a body so immensely distant, and presenting a minute disc even when highly magnified, little success could be expected. Mr. Lassell expressed himself confident that on October 3rd, 1846, he had discovered a luminous ring surrounding the planet, so that in fact the unique figure of Saturn was repeated. On several subsequent occasions the same observer satisfied himself as to the reality of the phenomenon, and in this he was confirmed by Professor Challis, who saw the ring both on January 12th and 14th, 1847, and estimated that the ratio of its diameter to that of the planet was as 3 to 2. But though resting on the testimony of such excellent observers, it was found on renewed scrutiny that the idea of a ring must be abandoned, for no such appendage could be distinctly perceived in the best glasses. Mr. Lassell had, no doubt, been deceived by his earlier impressions of the figure of this difficult object, and we can easily understand the cause of the error. He had been looking for such an appearance as analogy suggested, and the ill-defined figure of the planet imperfectly shown in his telescope had caused him to explain it on erroneous grounds. But though failing here, Mr. Lassell was very successful in another respect. On October 10th, 1846, he obtained glimpses of a satellite of Neptune, for which he deduced a period of 5 d. 21 h. 8 m. This discovery was shortly afterwards confirmed, and traces of a second satellite were glimpsed, but it still awaits corroboration, so that at present we only have certain evidence of a single satellite attending Neptune.

After a certain amount of observation, new elements, based on observed positions, were computed for the planet. Its mean distance from the sun proved to be about 2,746,000,000 miles, and the period of its revolution about 165 years. The orbit was found to differ widely from that theoretically assigned to it by Le Verrier and Adams. Its distance from the sun was considerably less than that supposed, and it is distinctly opposed to Bode's law* representing the distances of the planets, which indicated in the present case the distance as 388, whereas it was found at 300·4. On this account some exception was taken to the reality of the discovery. It was even said that Neptune could not be the identical planet to which the original computations of Le Verrier and Adams had reference, but must have been accidentally situated at the position they had assigned. This attempt, however, to detract from the merit due to the discoverers signally failed.

We have already stated that Uranus, long anterior to its discovery by Herschel, in 1781, had been observed as a star, though not identified as a planet; and this is equally applicable to Neptune, for Lalande had seen it in 1795, without, however, detecting its planetary nature. The position it had occupied half a century prior to its discovery served a useful purpose in computing the orbit with a degree of accuracy which could not otherwise have been attained.

The large instruments of our own day have not revealed any new facts concerning the planet. No markings have ever been discovered upon its surface, so that the time of its rotation is a mystery. No additional satellites have been caught sight of, though it is admitted that the one discovered by Lassell in 1846 is not a very difficult object to glimpse. Possibly, the remaining satellites may be excessively minute, in this respect offering an analogy to the system of Saturnian satellites, one of which (Titan) far outshines the others.

But though our knowledge of the most distant planet is thus admittedly incomplete, we have lately been attracted to the consideration of the question as to whether there are other planets beyond the sphere of Neptune which, owing to their minuteness, have hitherto avoided discovery. Professor George Forbes has investigated the matter, and endeavoured to show, from a relation of the aphelion distances of comets with planetary distances, that there are probably two such planets, and he has made an attempt to deduce approximately the positions. The nearest planet he places at R.A. 11h. 40m. N.P.D. 87° in 1880, and the farthest at R.A. 22h. 0m. N.P.D. 51°; but the latter is very doubtful, and he only expresses himself confidently as to the position of the former, which, however, has not been found, though closely searched for at several observatories. We cannot here enter into an explanation of the reasoning by which Mr. Forbes has been led to such definite results,† but merely mention them to show the tendency to search yet farther afield for new orbs; and that we may anticipate such discoveries is evident by the energy of observers, and the capacity of recently constructed telescopes to reveal fainter objects than any which could be discovered by the instruments of years ago.

* "Science for All," Vol. IV., pp. 173-4.

† These will be found detailed in "The Observatory" for June, 1880, pp. 439—446.

WHAT IS UNDER LONDON?

By Frederic Drew,

Assistant Master at Eton College, Associate of the Royal School of Mines.

To find out what underlies any great city, although the knowledge of it is often of much use and sometimes even of vital importance, is not a thing that can be done easily or at any time that one may choose for the investigation. The surface is so covered by buildings, pavements, and roadways, and so obscured by the "made ground" (old rubbish-heaps and other artificial accumulations) in those parts which have been for long inhabited, that only occasional glimpses can be got of the true and once virgin soil. However, the excavations that not unfrequently diversify our streets (the object of which is in itself a matter of interesting speculation to the passer-by) yield much information. For my part, I rejoice to see a London street barred, and a great mound of earth and stones thrown up alongside of it, and to take note of the various soils thus exhibited. The Geological Survey of London was indeed made by the Government surveyors from observations on such chances, coupled with an examination of the records of former operations that had been kept by engineers and others.

The reply to the question propounded should, in the first place, satisfy those who wish to know what is immediately beneath their feet, down, say, to a depth of 20 ft.; those who may be anxious to know on what soil their dwelling is built, whether on gravel or sand, on clay or on chalk, and to consider the bearing of this on the healthiness of the situation. But the answer should go farther, or rather deeper, and should satisfy those interested in well-sinking, railway-tunnelling, and other engineering operations, and even those desirous or curious to know if there be any chance of our finding beneath London such mineral wealth as has, in other parts of our country, created centres of population and of industry. It need hardly be said that the subject, when treated in this way, is a geological one. The principles of geology have been so fully illustrated by various papers in this work, to several of which special reference will be made as we go on, that the reader must be credited with a knowledge of these sufficient for application to the case before us. At the same time, the details and explanations that will be given may recall and strengthen in the reader's mind the truths previously laid down.

The flattest and lowest parts of London claim our attention first. By this is meant physically, and not necessarily socially, the lowest. Alongside the Thames, sometimes on one side of the river and sometimes on both sides, is a spread of flat ground, which is in truth below the level of high water and has been reclaimed by man from the area that the flood-tide once covered. The inner boundary of this flat land is marked by a natural bank or rise of ground, except where it has become obscured by filling in or by the building of streets at a higher level, or by other artificial means. The tract includes portions of Battersea Park, of Pimlico, of Lambeth, and of Southwark. The inhabitants of these two last districts have reason to know what a low level they live on, suffering as they do every now and then from the invasion of a tide higher than that which the present barriers are able to exclude. Below Bermondsey the spread of this alluvium widens, while on the north or left bank of the river it is joined by a corresponding deposit of the Lea, the mouth of which river, at Bow Creek, once made a not inconsiderable branch of the Thames estuary. Now all that low part has for its soil mostly *clay*, commonly a bluish clay, which is nothing but the river mud that the river itself deposited when it had its own way—that is, before man began to embank the mud flats and make them his own.

Besides the clay, sometimes a layer of *sand* is found, for the river, in its various overflowings and shiftings, now and then drifted along and deposited sand as well as the more frequent mud. Again, in some spots a layer of *peat* is met with. Such an accumulation of vegetable matter was not deposited but grew on the spot. This shows that sometimes the marshes were left free enough from water for vegetation to take root in them.

These materials thus spread over the flat are called "Recent Alluvium." The word "alluvium" means that which is washed down from above, and deposited by a river, while the epithet "recent" is needed, as will presently be seen, to distinguish it from the next kind of soil.

Below London the low flat is much broader than above. As one steams down from the docks, the wider extent of marsh can be seen, from which the artificial bank or wall alone keeps out the rising

tidal waters. It has been remarked by Mr. Whitaker of the Geological Survey that we have here the true cause of the position of London. The reason that London was in very early times a place of importance is the same as that which makes it a *port* of importance now. It is there that the best access by sea is gained towards the heart of the southern portion of our island. The navigator was and still is carried onwards most easily and conveniently by the alternating tides until, instead of mere marshes, the dry gravel plains next to be described are reached, which, being high and dry, though not too high above and being close to the great highway of the tidal river, made a good site for dwellings accessible from it.

This leads us to consider the next tract, that of the *gravel*. Gravel underlies a considerable part of London and its environs, including the most favourite and perhaps the most healthy portions of the metropolis. It is not unlikely that in the early times of man's settlement here, the space occupied by the gravel was bare of trees and made a belt of open ground between the forest and the river marshes. This ground is at various levels; often it constitutes terraces at different heights, but sometimes it more gradually slopes upwards from the Recent Alluvium. Thus at South Kensington there seems to be a gradual slope upwards from the Chelsea district, some of which at all events is of the lower alluvium, to the South Kensington Museum and the Albert Hall, while along the Bayswater Road is a higher level terrace. Piccadilly, again, and the Strand are near the natural terrace-slopes of similar material.

The origin of such terraces as these has already been explained.* They are levels of an *older* alluvium. The river, by continually supplying from above more of the stony material derived from the waste of the Chalk Hills than it could manage to carry onwards, *raised its own bed*, spread the stones as it wandered to the right and left, and made a gravelly plain extending from hill to hill all along its course from Reading to London, and the level of that gravelly plain was raised as the accumulating process continued. Later on, for reasons about which geologists are not altogether agreed, the river *changed its habit*, and, instead of allowing material to *accumulate*, began to lower the level of its bed by carrying down towards the sea more stones than were supplied from above. In doing so, it cut out the present immediate valley of the Thames, and left terraces, as described in the paper before quoted; and the side streams cut down *their* channels correspondingly, so that these terraces are less continuous than they would otherwise have been.

* "Science for All," Vol. II., p. 336.

An opportunity is every now and then given, by excavations for a drain, a cutting for a railway, &c., of seeing what the gravel is composed of. The stones are clearly half-worn chalk flints. The river action, by which they have been transported maybe forty or fifty miles, has rubbed off the most projecting points, but has not converted them into smooth round pebbles. Between the larger flint stones smaller fragments of the same occur, as well as sand. This last also is sometimes found in distinct beds among the beds of gravel.

All this is called the "valley gravel" of the Thames. This name distinguishes it from certain other masses that lie beyond the range of the present paper.

It should be added that of the same age and of similar origin are certain spreads of brick-earth, or loam—which was a more sandy mud. This was made by the spreading river carrying silt of that kind, and leaving it here and there in the stiller portions of its waters.

The beds of gravel, besides affording a dry and healthy soil for the site of a house, also contain water at a slight depth. In sinking to from 12 to 30 feet water can generally be found; such accumulations are now for the most part superseded by the water-works, but before the region was so crowded such wells gave a convenient and good supply to the inhabitants. These facts demonstrate that at no great depth a change takes place in the material of the soil. It is the occurrence of *an impervious stratum* that allows the rain water that has been able to filter down between the stones of the gravel-bed to accumulate. The well is sunk just into this lower stratum, and from the hollow we can draw water that continually flows or dribbles in from all sides.

This impervious stratum is a thick bed of clay, which (with the exception of certain portions to the south-east) underlies the whole of London. Either it is to be found beneath the "Recent Alluvium," and the "valley gravel and brick-earth," or it constitutes the surface soil. In either case it will be found to continue downwards for a hundred or more feet. This is that which one sees turned up in certain districts of London and the suburbs as a brown, sticky, smooth clay. If, however, it were got from far down, as in a deep well, it would oftener be found blue than brown, the brown colour

near the surface being due to a kind of *rusting.* Such is the *London Clay,* a name well known in the neighbourhood, and well known in the wider area in which geological nomenclature is familiar. Looked at as part of the sub-soil of London, it is undoubtedly the least favourable for dwelling on, and it occupies some of the less favourite quarters of the town. London was built first on the gravel, but in spreading it occupied some of the adjoining clay land. It is likely that when a space of clay land thus built over is completely occupied, paved, and drained, there comes to be far less difference in point of salubrity than there was at first between it and the gravel tracts.

For a thorough understanding of the way in which the different soils thus far enumerated are distributed, a map such as has been constructed by the Government Geological Survey is necessary. Or, better still, the raised map or model may be consulted which stands in the large room of the Museum of Practical Geology, in Jermyn Street. We must here be satisfied by a slight sketch only of the distribution. From the Tower westward for some miles a terrace-slope of gravel faces the river, with a break where the valley of the Fleet comes in at Blackfriars; west of Trafalgar Square this terrace may be said to branch into two, one being that of the line of Carlton House Terrace, while the other is the higher level of Piccadilly. The London Clay comes to the surface between these two, and continues in a narrow strip along the hollow of the Serpentine towards Westbourne Terrace, while a branch strip runs westward through the lower part of Kensington Gardens to Holland House. Southwards from this line a lower level of gravel extends (including that on which South Kensington is built), which either continues to the river or gives way to the clay of the Recent Alluvium. Northwards from that line of terrace-slopes a large gravel area extends, which is completely built over. The farthermost districts are Hackney, St. Pancras, and all south of the Marylebone Road. A little north of that road the clay begins which extends throughout the northern suburbs, including St. John's Wood and Regent's Park, and the slopes upwards towards Hampstead and Highgate, but not, as will shortly be seen, the summit of the hills that bear those well-known names.

On the south the arrangement is at first similar, but it ends differently. Going, for instance, towards Clapham, one would, on leaving the lowest flat, pass over a low-level gravel; then, on rising, pass a narrow strip of clay, which is capped by a higher-level gravel that makes the plateau of Wandsworth and Clapham Commons. A somewhat similar succession is found at Putney; Putney Heath and Wimbledon Common together constitute a plateau, which is, as it were, an island of gravel surrounded by clay, for as soon as one goes a little way down the surrounding slopes clay appears at or shows signs of its proximity to the surface.

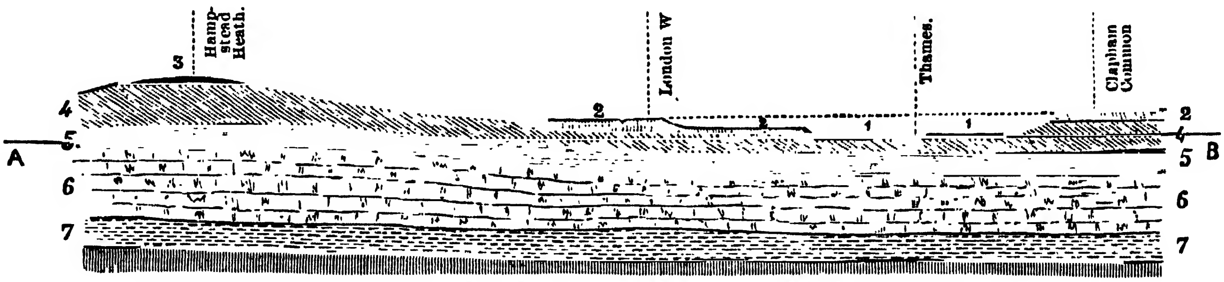

Fig. 1.—Geological Section of the Thames Valley from Hampstead Heath to Clapham Common.

Superficial Deposits:—1, Recent Alluvium: 2, Gravel. Tertiary Formations: 3, Bagshot Sand; 4, London Clay; 5, Lower London Tertiaries. Secondary Formations: 6, Chalk; 7, Upper Greensand and Gault. The line A B denotes the level of the sea; the dotted line from terrace to terrace shows the height to which the gravel had accumulated, and the hollow beneath that line represents the extent to which it was afterwards worn away till the valley, in nearly its present form, was made.

In some parts the gravel is replaced, as it were, at the same level by brick-earth. The largest spreads of this brick-earth (which in character is intermediate between sand and clay) are from Royal Crescent, Notting Hill, westward, at Highbury, and at Stoke Newington.

It would be inadvisable to express further in words what can so much better be expressed in a map, and perhaps this sketch will enable the reader to find more in the geological map than he otherwise would. He will be helped to a clear understanding of it by the annexed section, drawn as from Hampstead to Clapham Common. (Fig. 1.)

As to the London Clay, it must be understood that the original thickness of it all over these parts was the same, or about the same, as is now seen beneath Hampstead, where close upon 300 feet of it is capped by the next formation in the series of deposits that were made beneath the sea

long before any of the present ground about London was shaped, which capping of sand also extended as a great layer over the whole of our area; for in going back from the epoch of the formation of the gravel to that of the clay, we step over great periods of time—periods during which much happened on the earth that is here unrecorded. These periods are those to which geologists have given the names (going backwards) of Pliocene, Miocene, and, according to some authors, Oligocene. That period of a portion of which the London Clay is a record is called Eocene.

To bring our minds to understand the state of the geography of England in the Eocene times requires a much greater effort than we have yet been called upon to exert. For hitherto we have had to imagine the Valley of the Thames in a somewhat different state and form, but now we have this part of England with no Thames, the hills about London as non-existing, and the very material of which they are made as but beginning to arrive. That the London Clay was formed in the sea from the waste of some old land there is the best of evidence (Vol. IV., p. 315). When good openings in it are to be seen, such as that which a well or a railway cutting freshly made may give, or, better, when it is exposed at a cliff, as is the case in the Isle of Sheppey, a rich assemblage of fossils is found in it.

The meaning and import of fossils have already been explained.* An examination of the fossils of the London Clay will tell us much. Of marine shells—the moving houses of various denizens of the sea—we find nearly 300 kinds; the names of some of these are so familiar to many that they are worth repeating for the sake of giving some idea of the richness of our sea at that time in this kind of population. There lived some half a dozen different kinds of *Nautilus*, together with some of those allied creatures (different as they are at first sight, from their possessing no external shell), the Sepia, or Cuttle-fish. Then, of "Gasteropoda" are found *Conus, Voluta, Murex, Bulimus, Natica, Cypræa*, and many another; of "bivalve" shells, *Pecten, Avicula, Cardium, Cardita, Pinna, Solen, Modiola, and Teredo.* The class Crustacea is represented by numerous crabs, and fishes were there in great variety. But besides these and many others which tell of the sea, there are found some fossils which indicate that land was not so far off but that things could be drifted from it to our sea-bed. Remains of turtles and tortoises and of land birds have been found, and in some parts many specimens of the fruit of a species of palm-tree, called Nipadites, a tree the like of which grows on the land fringing large rivers in their lower courses. Hence it is believed that though the London Clay is marine, yet it was deposited outside the mouths of a great river, its sediment being supplied by that river. But these fossils tell us more. They tell of a climate different from our present one, of seas warmer. Palms now grow no nearer to us than the south of France; the living shells most like those of the London Clay are, if not tropical, yet of distinctly warm regions. Such a light do fossils throw upon ancient geography that the depth and temperature of the seas that covered our country at various ages can even now be stated with a closeness that brings before us truths of great interest and magnitude, while in the future, especially if more voyages like that of the *Challenger* be carried out, we may hope for a near approach to certainty of detail.

The mud thus deposited spread over an area which may be likened in extent to that of half a dozen counties. Intermediate portions of it have since been removed, but the extreme points at which it is now found are in Dorsetshire and Essex, in Wiltshire and Sussex, and it doubtless once existed still farther in every direction.

This is the time to speak of that patch of sand found on the summit of Hampstead Hill, which is represented by the number 3 in our section (Fig. 1). Hampstead Heath, with its level summit, its slopes and dells, has for its soil sand, as can be seen at many openings which have at various times been made for that material. Mr. Whitaker indeed asserts that so much has been dug away that little of the original surface of the ground has been left. Nowhere, probably, was there a greater depth of sand than 80 feet. It rests nearly level upon the London Clay. The boundary of the patch, or, as it is called, "outlier" of sand can pretty well be traced. Going down almost any of the slopes one will meet with some indication of water coming out—a spring, for instance, or a swampy bit of ground. This denotes the level of the plane of junction of the two formations at that particular spot. The rain-water that falls on the Heath is absorbed into the sandy soil, trickles down till it meets the impervious London Clay, spreads right and left till it finds an outlet where the "plane of junction" reaches the light; in other words, at the *outcrop* of the junction of the two beds.

A similar, but smaller, patch of these sands

* "Science for All," Vol. I., p. 64.

occurs on Highgate Hill; there is one on Harrow Hill, and perhaps one in Richmond Park. The greatest extent and thickness of the formation is to be found fifteen miles and more from London—at Esher, Virginia Water, Ascot, Aldershot, and Bagshot, from which last place the name has been taken. Geologists have no doubt that the outliers just mentioned were connected with this main mass, and are but the relics of a great sandy deposit that was once perhaps co-extensive with the London Clay.

The formation of the Bagshot sands was in this wise. When the whole of the London Clay had been deposited in still water, the sinking movement of the sea-bed that had been going on became arrested, and perhaps changed to one of upheaval. The now shallowed sea became affected by waves and currents that were able to spread upon it the coarser deposit of sand, which was brought also from the wasting land, but perhaps from where it was being wasted by the action of the waves around its coast. There is little doubt that the continent of that time, as well as of the period of the London Clay, was to the north and north-west of the area of deposition. The numerous marine animals before spoken of no longer flourished in the uncongenial conditions of the shifting sand; few, if any, existed; the shells of none have been preserved, or, at least, none have been discovered. This lower part of the Bagshot sand is "unfossiliferous." At some period later than this the whole area was uplifted from the sea and was made into land, the form of which soon again began to be modified; but many ages elapsed before our plains were made and the hills brought to their present form. As to the time when this happened, we may say that this process of denudation may have been going on from the Miocene period onwards. The agencies exerted have been explained,* and may be enumerated as the sea, with its waves and currents, rain, rivers, and weather in every form.

The question now comes on "What lies beneath the London Clay?" Well-sinkings that have been made enable us to answer this directly. Everywhere it rests upon a somewhat mixed or varying mass, which yet may accurately be described as a thickness of 100 feet or more of sand, with some clay, and some beds of flint pebbles. These strata (which collectively bear the name of "Lower London Tertiaries") have been subdivided, and these subdivisions have been carefully traced whenever they come to the surface. For our purpose, however, they may be treated *en masse*. Only a list of their somewhat varying parts is here given in a note.†

If our section were continued farther to the north, or to the south, or if another section were drawn at right angles to this one, then it would be seen that towards the north and south, and east and west, these lower beds come nearer to the surface, until they *crop out* and occupy an area of the land, all above having been removed. Close to London it is at the south-eastern outskirts that this has happened; first at Nunhead, then at Blackheath which is covered by the uppermost of these strata, namely, the thick pebble bed. It is this that gives the peculiar character to the heath, and to the continuation of the same plateau towards Erith, while the rising ground on the south of this line is occupied by the London Clay.

Fossils are by no means regularly distributed through this formation, but at certain localities and at certain horizons, or strata-levels, shells of several species occur. Sometimes these are marine, sometimes they show what are called "estuarine conditions," that is, they belong to those species of animals that frequent estuaries, where the water is brackish, or half-salt. These include, among other kinds, a variety of oyster, which is common in these beds at Woolwich, and which can often be obtained in such a state as to give a proof, convincing to the least educated, of the marine or estuarine origin of the material it is found in. Land must have been nearer during this period than during that of the London Clay. The presence of pebbles denotes this, and the varying character of the deposit also. *What* was that nearer land that was wasted to produce these lower strata is not altogether clear, though, if the reader will remember that the pebbles in them are made of *flint*, he will shortly find that the fact will afford him a clue to a portion, at all events, of the mystery.

The next formation downwards in succession is the well-known material chalk. Everywhere beneath London, as has been proved by many a well-sinking, there lies a mass of chalk, several hundred feet thick. Those wells or borings that have gone through it and reached to another stratum, show

* "A Highland Glen:" "Science for All," Vol. I., p. 33; "Hills, Dales, and Valleys," *Ibid.*, Vol. I., p. 116; and "Rivers and their Work," *Ibid.*, Vol. I., p. 208.

† *Oldhaven or Blackheath beds*—a thick bed of pebbles and sand.

Woolwich and Reading beds—sometimes sand, sometimes clay; shells frequent.

Thanet beds—fine buff sand, without fossils.

that it is about 600 feet thick. Going to places north and south of London, we find that the chalk bends or dips upwards in each of those directions, at last coming to the surface; then it makes a tract of hilly ground stretching far from east to west, or from north-east to south-west. A geological map of England shows by its colouring the space of ground thus occupied by the chalk; our explanation of the London area will have made it clear that wherever Tertiary formations are coloured on such a map, the chalk underlies them; and it must also be understood that the chalk once extended over some of those parts which are now covered by the strata older in the series than the chalk. Over the tract intervening between the Kentish and the Sussex Downs the chalk once extended, and north-westwards it stretched beyond the chalk hills of Berks, Bucks, and Cambridgeshire, over Central England, diminishing, no doubt, in thickness. It is certain that during the Chalk Age a great portion of both England and France was beneath water, under those conditions described in a former paper,* which conditions, we have seen, now prevail in a large part of the Atlantic and Pacific Oceans. That is to say, on the southern portion of our island and part of northern Europe, a white or grey mud or ooze was accumulating from the fall of the minute shells of Globigerina, to which were added the remains of many other marine animals, but sandy or muddy sediment was quite absent from the area at that time, the ocean being clear, though probably not one of great depth.

One or two details about the chalk must be given. It is not quite the same all the way down. The upper portion contains the "chalk-flints," which are irregular masses varying much in size, from the size of a walnut to several times that of one's head. Now, it is these flints (derived from the chalk of other parts) that are the source of the flint pebbles which occur in a well-rounded state in the lower London Tertiaries. This shows that *some* of the chalk had been upheaved, and had formed land before or at the commencement of the Tertiary period; thus some of the land is accounted for, which, being wasted, produced the Lower Tertiary strata.

Again, it is these same flints that make up the gravel that to so great an extent fills the Thames Valley. The Thames drains a large extent of chalk hills; these often have for a covering a layer of loose unrounded flints, which were got together by the gradual dissolving away of many feet of chalk that contained them. These flints have been, little by little, washed down into the streams and so reached the Thames, which then rolled them along and spread them over its bed.

To go back to the chalk. The lower portion is completely free from flints. Lower still it becomes less pure and white; it is, in fact, "grey chalk." Lowest of all is "chalk marl," which is a whitish, friable substance when dry, but grey when wet, and then holding together from an admixture of argillaceous or clayey matter. Now, with respect to water supply—for which object the borings or well-sinkings into the chalk have been made—it must be noted, first, that the purer chalk is the portion of the formation that *contains* water, while the lower portions—the grey chalk and the chalk marl—oppose the downward passage of the water, or hold it up. A great number of wells have been sunk, from 100 to 300 feet deep, into the chalk; but the demand for water has increased beyond the supply from them; hence enterprising firms have purposed to obtain a larger supply by penetrating the grey chalk, and another bed yet more impervious that is known to underlie it, to see if haply a yet lower formation might give the needed supply. In thus sinking, it was found that the chalk is underlaid by a certain sandy-chalky bed, called the Upper Greensand, and then by 150 feet of a *blue clay*, which also is well known where it crops out or comes to the surface north and south of London, and which bears the name of 'Gault."† This bed seems almost everywhere to have preceded the chalk. The deposition of its material and the subsequent clearing of the sea, though not thoroughly accounted for, seem to denote a gradual submergence. Its fossils generally resemble some of those of the chalk, though differing in species and wanting in those kinds characteristic of a more open oceanic area. The hopes of a large supply of water on this bed being pierced—and it has been pierced at a depth of 1,000 feet from the surface—were not fulfilled. What *was* found beneath the Gault, what hopes have been raised by that find, and what foundation there may be for those hopes, cannot find a place here, but the demonstration of them may, perhaps, be described in another place.

* "Science for All," Vol. I., p. 9, and Vol. V., p. 65.

† In the section the Upper Greensand and Gault are massed together, and numbered 7.

HIBERNATION OF MAMMALS.

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THE hibernation of animals is a point in natural history which must have forced itself on the least observant of country residents. But what is "hibernation?"

The "theory of surrounding influences" * was a favourite subject with the older naturalists. Their successors ascribe to it the weight of established truth as the "doctrine of environments."† The former insisted on the adaptation of animals to the climatal and other conditions of their areas of distribution, as the protest of science against the assumption that external influences explain the growth of organs and determine their forms; the latter appeal to the adaptation in order to re-affirm the so-called doctrine. Both sides might find much to interest them in the subject of this paper. We wish to keep clear of speculative views, because it is really of no moment for our present purpose whether habit is the outcome of original impress, or simply the expression of a countless crowd of influences active throughout untold generations, and now the definite representation of natural law.

This reference to surrounding influences leads us to the heart of the topic now before us. As to climate, man meets its ever-varying seasonal conditions by the forth-putting of inventive and adaptive intelligence and skill to provide suitable covering. In the case of the lower animals, the provision is natural and ready. As to food, man is not wholly dependent on the supply within the area of his distribution. Among the lower animals demand and supply are both natural; there is no taking thought, as with man. But the animal may inhabit an area where the supply fails at regular intervals, and if the appetite continues active exceptional instincts and conditions of life must come into play. It must either leave the locality, or instinct must work in a way generally ascribed only to intelligent forethought, or a state must intervene in which conditions favourable to the preservation of the species without feeding must be superinduced. The first gives us the migration of mammals, the second their habit of storing food for winter use, and the third their hibernation, or the habit of winter sleep. The first has been dealt with in a former paper (p. 142), the other two fall now to be considered.

There is a pretty gradation of habit here which has been hitherto overlooked. We see the storing instincts undergoing modifications, and gradually sloping into the darkness of deep winter lethargy. Let us trace the steps. There are, first, the animals which store food for the winter, but do not hibernate. They have no long periods of sleep, and are of interest here only because they link on to forms which have. The long-tailed field-mouse (*Mus sylvaticus*) is one of the best known of this group. Each mouse lays up its own hoard of corn, the seeds of flowers, acorns, &c., in some deserted mole-run, or among heaps of stones, at the base of old walls, at the roots of trees, or under the thick moss in unfrequented roads and hedgerows. It makes sure while the sun shines of an ample supply for winter use. Autumn diligence sets it free from winter care. But it is in the family *Sciurina*, or squirrels, that we best see the link between non-hibernating and partially hibernating mammals. Some well-known American forms belong to the former; our own common squirrel introduces us to the latter. The chickaree, or Hudson's Bay squirrel (*Sciurus hudsonius*), stores up great quantities of hickory-nuts, butter-nuts, chestnuts, and hazel-nuts. Audubon saw a bushel and a half of these taken from a hollow tree occupied by a single pair of these industrious creatures. The four-striped ground-squirrel (*Tamias quadrivittatus*) is noted for similar habits. It is a curious fact that these forms often, if not always, hoard more than is required for the winter use. Instinct overshoots necessity. The laboriously-gathered supplies of the previous autumn go to waste when summer comes with its sufficiency or its superabundance of food. The beaver is another good example of a storing but non-hibernating animal. Bark is their chief article of food, though they also feed freely on the juicy roots of water-plants. Its mode of keeping the barks soft and succulent for winter use is by cutting off the green branches of the willow, the poplar, the birch, &c., and carrying them to its dam, where they lie under water during the winter. We come, secondly, to the animals whose hibernation is either partial and interrupted, or complete. Hibernation

* Bell: "The Hand," chap. vi.

† Spencer: "Principles of Biology," Vol. I., pp. 80—90.

may be incomplete. (*a*) Mammals which hoard hibernate interruptedly, and come occasionally or frequently abroad during winter. These, it will be seen, for the most part belong to the order *Rodentia*, or gnawers, as, indeed, do most of the true hibernates. The common squirrel (*Sciurus vulgaris*) is an excellent example under this head. This pretty, nimble, gentle, playful, little rodent begins in mid-autumn to gather hazel-nuts, acorns, beech-mast, fir cones, which have come too late in the season, and the like. These it stores away in different places, near to its winter retreat, a dome-shaped nest of intricately arranged twigs, lined chiefly with leaves and moss, but sometimes having tufts of wool and a stray feather or two picked up at random. Throughout late autumn and early winter it rigidly abstains from breaking in upon its stores. When winter fairly sets in, it betakes itself to its warm nest for considerable periods of deep sleep; but whenever a peculiarly mild day comes it leaves its abode for a lively gambol among the branches, visits one of its many stores, makes a hearty meal, and retires again for days or weeks of unbroken slumber. The habits of the chipping squirrel (*Tamias lysteri*), a related American form, bear some resemblance to those of our common squirrel. It is, however, gregarious, and lives in burrows, from which numerous galleries branch off. In these, great abundance of different kinds of nuts, Indian corn, &c., is hoarded. (*b*) Mammals which do not hoard, whose hibernation is more sustained, but which occasionally come abroad. Some bears and some bats are of this sort, though no sharp and definite line can be drawn between them and true hibernates, because, in the case of the bears, at least, there is a difference in the habit of the sexes as regards this. The grizzly bear (*Ursus ferox*), huge, fierce, active, occurs as far north as 61°, and is met with also in the south of Mexico. Richardson says: "The young grizzly bears and gravid females hibernate." But even they are known to come abroad before the snow is off the ground. Thus they differ from complete hibernates. The old males come habitually abroad

Fig. 1.—The Common Bat (*Vespertilio pipistrellus*) in Flight.

during winter. The polar bear (*Ursus maritimus*) is essentially an Arctic animal, and there can be no necessity for hibernation on its part, so far as food is concerned, because food abounds throughout the year in its natural habitats. The pregnant female alone retires to a winter den or burrow, in deep snow-drifts, where she remains without food from the end of November till the end of March. Meanwhile two tiny cubs are born, and with these now as large as shepherds' dogs, she comes forth in spring. When the female betakes herself to her *hibernaculum* the male goes out to sea on the ice, feeding chiefly on seals. It is a noticeable fact that the non-pregnant females wander free throughout the winter like the males. A good deal of uncertainty prevails as to the habits of the black, or sloth bear (*U. labiatus*) of India. Mr. Sanderson* says: "It does not hibernate, and though covered with so thick a coat, seems quite at home in the hottest localities." Captain Baldwin† remarks, "I need hardly mention that the different species of *Ursidæ* inhabiting cold climates hibernate. I am unable to state for certain whether *U. labiatus* is given to this practice or not, but I imagine he is an exception to the rule, and *does not* hibernate." It is likely that this difference of opinion has its origin in the partial hibernation of the animal.

I have referred to the bats (*Chiroptera*). Personal observation leads me to give the common bat, or flitter-mouse (*Vespertilio pipistrellus*, Fig. 1), a place under the present head. I have often seen it abroad in the winter months. It retires to its *hibernaculum* when the cold weather has fairly set in, and comes generally out in early spring. But even when snow is on the ground it may be seen skimming fleetly around its summer haunts, whenever an exceptionally mild day arrives. While, however, the hibernation of the pipistrelle is thus broken and irregular, there are, no doubt, other species whose lethargy is unbroken from December till the end of February, and whose proper place is with the forms whose hibernation is complete.

(*c*) Mammals which store for winter, but do not come abroad; such as the dormouse (*Myoxus avellanarius*). "Towards the winter it becomes exceedingly fat; and having laid up a store of food, retires to its little nest, and coiling itself up into a ball, with the tail over the head and back, becomes completely torpid. A mild day calls it into transient life; it then takes a fresh supply of food, and relapses into its former slumber; and finally awaking in spring, at which time it has lost much of its fat, it enters on its usual habits" (Bell). To this group also belong the hamster (*Cricetus vulgaris*), and some American squirrels, as Parry's marmot-squirrel (*Spermophilus parryi*), and Douglass's squirrel (*Sciurus douglassii*).

In other cases there is complete hibernation. The American black bear (*U. americanus*) and the common brown bear (*U. arctos*) are both hibernates. The former inhabits the wooded districts of America from the Atlantic to the Pacific, and from Carolina to the shores of the Arctic Sea. Its *hibernaculum* is a hollow, scratched out under a fallen tree. To this it retires at the beginning of winter. When the snow falls around it the warmth of its breath makes a small opening in its den, and by this it keeps a connection with the outer air. "The Indians," Sir John Richardson tells us, "remark that a bear never retires to its den for the winter until it has acquired a thick coat of fat; and it is remarkable that when it comes abroad in the spring it is equally fat, though in a few days thereafter it becomes very lean." The habits of the brown bear correspond. The American skunk (*Mephitis chinga*) may also be named as another of the *Carnivora* whose hibernation is complete.

I hesitated before giving the hedgehog (*Erinaceus europæus*) a place under this head, because, though it is generally named as one of the best illustrations of hibernation, I can vouch that it comes abroad at night, even when snow is on the ground. This comparatively rare habit, however, seems confined to individuals, and is not characteristic of all the species. On the approach of winter, the hedgehog rolls itself up into a ball, and goes to sleep amongst the soft moss and the withered leaves it has gathered into its hole at the roots of trees. A favourite retreat of several confined in a walled garden was a thick bed of ivy at the base of an old yew tree. We must, however, refer to the rodentia for the best illustrations of the true hibernating habit. Taking the family *Sciurina*, and the genera *Arctomys*, *Myoxus*, and *Spermophilus*, it may be said that all species under the first are hibernates proper, and all under the other two are incomplete hibernates. The non-storing and true hibernating species are known severally as prairie-dogs, whistlers, burrowing-squirrels, mountain badgers and woodchucks, or ground hogs. The term marmot includes all these. The wood-chuck, or Maryland marmot (*Arctomys monax*) may be taken as a typical hibernating mammal. It betakes itself to its burrow when the first frosts of autumn appear, and remains in it until

* Sanderson: "Wild Beasts of India" (1878).

† "Large and Small Game of Bengal" (1877).

the grass has sprung up, and genially warm weather has set in. "Its burrows," Audubon remarks, "are sometimes extended to the length of twenty or thirty feet from the opening; for the first three or four feet inclining obliquely downward, and the gallery being continued farther on, about on a level, or with a slight inclination upward to its termination, where there is a large round chamber, to which the occupants retire for rest and security."

The facts stated above suggest questions peculiarly interesting and curious, yet surrounded with difficulties. Is hibernation a substitute for migration? Is the hibernating habit limited to animals whose area of distribution is either Arctic, sub-Arctic, or low-temperate? Is there any special significance, and if so, what is its import, in the facts recorded under sections *a*, *b*, and *c*? Do the structural features of hibernating differ anywise from those of non-hibernating but closely-related mammals? Each of these questions admits of very wide and varied discussion and illustration. We may, however, before concluding, indicate briefly the bearing of recent information on them. It has been too hastily assumed that hibernation is nothing more than nature's substitute for migration. Birds, it is said, migrate; mammals hibernate. But mammals migrate as well as birds, and in as true a sense. It is forgotten, that in some mammals the capacity of flight and the power of wing are as much developed as in birds. Yet bats do not migrate. Again, temperature is, no doubt, a more influential factor in hibernation than in migration. Yet even here there are facts which forbid us to push this too far, as if it were the sole and absolute predisposing

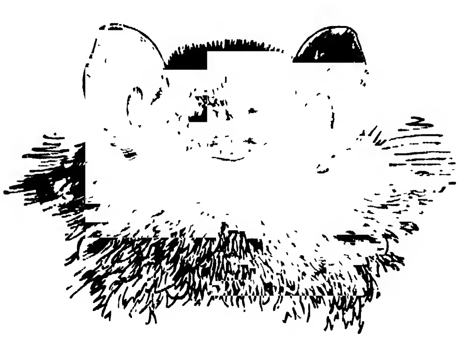

Fig. 2.—Head of Noctule (*Vespertilio noctula*).

cause. For example, even among our own bats there is one—the noctule (*Vespertilio noctula*, Fig. 2)—which retires to its winter sleep about the end of July or the beginning of August; that is, before the commencement of the cold weather. And Humboldt has pointed out that the hedgehog-like tanrec (*Centetes*) falls into a three-months' sleep even within the tropics. Thus *C. ecaudatus* (Fig. 3), introduced from Madagascar into the Isle of France, fell into the lethargic condition at Port Louis, where the mean temperature is 7° Fahr. above the hottest month in Paris. Does this point to the absence of food as the predisposing cause? We know it is so in the case of some amphibians, because there are tortoises which can remain without injury for months enclosed, at the dry season, in parched mud. As regards the gradation in the hibernating habit, fully noticed above, it would lead us outside of the purpose of this paper to do more than say that speculative naturalists might find it to be richly suggestive, both from the standing-point of current views of heredity and of the doctrine of environments.

A good deal of attention has been given by Continental and British observers to the structural and physiological relations of this habit. The alleged analogy between hibernation and common sleep, the bearing of atmospheric temperature on the temperature of the body in its lethargic state, the changes in the action of the respiratory and digestive organs, and the curious association of a quickened circulation with a retarded respiration, have all received much thoughtful consideration. The results of experiment and research may be briefly stated:—1. Though there are many points of resemblance between ordinary and hibernating sleep, yet the latter differs by inducing a more impaired state of respiration, by the augmented power of bearing the withdrawal of atmospheric air, and by the increased giving-off of heat. "The power of supporting the abstraction of oxygen is peculiar to the hibernating state." A bat the temperature of whose body was 36° Fahr. was immersed in water at 41°, and continued under it for sixteen minutes without injury. A lethargic hedgehog, whose temperature was 40°, was immersed in water at 42°, and continued under it for twenty-two and a half minutes uninjured. If the hedgehog were treated thus when in an active state it would be drowned in about three minutes. 2. The temperature of the hibernating animal follows the changes in the temperature of the atmosphere. 3. The irritability of the heart is augmented. This seems to explain the continued sensibility characteristic of the hibernating state. 4. Hibernation differs from torpidity. The latter is marked by stiffened muscles, greatly retarded circulation, and by insensibility. But even

severe cold, and, indeed, any cause of pain, will rouse the hibernating animal; it is not so in torpidity.

Why, then, do some species of mammals hibernate, while some closely related species, within the same geographical area, under identical physical conditions, and substantially living on the same kind of food, do not hibernate? It must be owned, even in view of the facts and inferences which crowd this paper, that a perfectly satisfactory answer to this question cannot yet be given. The subject has long had the attention of naturalists. Many facts have accumulated, but not so many as to warrant a complete integration. Much remains to be done—much land to be possessed; and what is now wanted is a thoroughly scientific examination, by a competent anatomist, of the structural differences during winter, if any, among the forms named under *a*, *b*, and *c*. Hitherto, observers have dwelt too much on what (*a priori*) they think ought to be. They have not stated clearly and definitely what the facts of the case actually are. Original observers will find the field one of rich promise. The history of few British hibernating animals is exactly known: that of the species living in other countries is still more obscure.

Fig. 3.—The Tanrec (*Centetes ecaudatus*).

HOW WAVES OF LIGHT ARE MEASURED.

By Professor Josiah P. Cooke, LL.D.,

Havard University, Massachusetts.

FEW persons have an adequate conception of magnitudes which greatly differ from the dimensions of their own bodies. Indeed, the earliest and the natural measures of length—from which all other measures of magnitude are derived—were the length of the foot, the length of the arm, or the length of the pace in walking; and when the necessities of civilisation demanded more constant and exact measures than such variable standards, a rod of wood or metal was taken corresponding to

the dimensions of these natural measures, and arbitrarily declared to be the legal standard. Our English yard is said to be the length of the arm of King Henry I., and with all the attempts which modern science has made to discover an invariable natural standard, we still use the same primitive measures, only defining them more precisely. The standard yard is simply the distance, measured at a definite temperature, between two points on a definite rod, and on the careful preservation of this rod and of its copies, the integrity of our system of measures depends; and if this rod with all the trustworthy copies were destroyed, it would be impossible to restore the standard with the degree of accuracy required in the scientific investigations of the present day.

With the standards in ordinary use, both of measure and of weight, we acquire by long experience tolerably clear conceptions, but with most persons these conceptions are of very slow growth, and are extended with difficulty. Hence the opposition to the general adoption of the French metrical system, in spite of its obvious advantages. We have learnt what a yard is, what an inch is, and what a pound is, and these words convey to us definite conceptions; but it must take a long time even for educated people to acquire the same clear idea of a metre, a centimetre, or a gramme. The same is true when we attempt to multiply or subdivide our familiar standards beyond a very limited extent. An engineer, or the general of an army, will estimate the distances around a commanding position with a great degree of accuracy; but to most persons a mile means no more than a fifteen minutes' walk; that is, we conceive of it only through its relations to some other quantity. Much more is this the case when on studying astronomy we learn that the sun is ninety-two million miles from the earth. This statement conveys to the average mind no conception whatever except a confused impression of immensity, and if we attempt to assist the imagination by adding, that it would require a railroad-train, travelling thirty miles an hour, 350 years to cross this space, we simply appeal from an absolute to a relative measure. This is a perfectly legitimate method, and one which we constantly use both in investigating and in teaching science. By using one standard of relative measure after another, we are able to lead the mind farther and farther on until it is able to reach the sublimest truths of science. In astronomy, the velocity of light helps us to grasp the enormous distances with which it deals.

Master Michelson, of the United States Navy, has remeasured the velocity of light with such improved instruments, that great as the velocity is, 186,380 miles per second, he feels confident of his result within fifty miles. Without taking the successive steps by which the result has been reached, no one can form an adequate conception of such a velocity; but having reached it, we have at once a measure by which we may gain some idea of the vastness of the universe of matter. Compared with this measure, the dimensions of the earth itself are insignificant, for a velocity like that of light is capable of girdling the earth's equator nearly eight times in a single second, and light actually crosses those ninety-two millions of miles between the earth and the sun in eight minutes and fourteen seconds, or starting from the sun on its journey to the fixed stars, it leaves the whole solar system behind in four hours and eight minutes. But the swift messenger has then just started on his journey, and when we learn that it will require three and a half years to reach *Alpha Centauri*, our nearest neighbour among the suns of space, the imagination begins to mount; and when we strain our eyes through the telescope to distinguish points of light in the haze of the Milky Way, and cannot resist the conclusion that these luminous points are suns on the opposite borders of a cosmical ring, like that of Saturn, and that so vast are the dimensions of this ring that the light by which we glimpse those points started on its way before the opening of human history, we may, while we are awed by the presence of the infinite, find aspiration and hope in thoughts which can compass such bounds.

But why dwell on facts apparently so remote from the subject-matter of this paper? Simply because the magnitudes with which we are to deal are as far removed from our ordinary experience on the one side as are the magnitudes of astronomy on the other, and the truths we have to present will not be grasped unless the mind is prepared to receive them. The popular mind accepts the grand conceptions of astronomy because it has been educated in those ideas; but when told that a lump of sugar is a universe of moving worlds it ridicules what appears to it as the wildest speculation; and yet the latter conception is as legitimate a deduction of science as are the former. The certitude may not be as great in both cases, but the conclusions are equally sober scientific deductions from observed phenomena. And when we reflect upon it, why should we not expect to find a universe

below us as well as a universe above us? Is it probable that a creature capable of studying the cosmos should have been placed on its extreme border? Certainly there is no inherent absurdity in the conception of molecular magnitudes, and if, instead of bewildering the mind with vast inconceivable numbers, we seek to lead the imagination by such aids as we used in astronomy, we shall gain the assurance that we are able to weigh molecular masses and measure molecular spaces with as much accuracy as the distances of the fixed stars.

That same swift messenger, light, whose constant rate of motion gives us a measure of the vast celestial spaces, serves also—most wonderfully—to measure the magnitudes of the molecules. Along the lines of motion, which radiate in all directions from every luminous source, light is transmitted by very rapidly-succeeding tremors, or vibrations, at right angles to the direction of the motion, and any single line of transmission takes the form of a water-wave. Let A B (Fig. 1) represent such a line, then the distance a b between two succeeding crests, or the distance a' b' between two succeeding troughs, or in general the distance between any two succeeding particles, as a'' b'', in the same phase of their motion, is called a wave-length. Such a line of motion as this constitutes a ray * of light, and while the luminous energy is transmitted from one particle to another along the line—just as in a familiar experiment mechanical energy is transmitted along a line of suspended ivory balls—the particles themselves only oscillate backwards and forwards across the line of transmission, and the distance between any two succeeding particles in the same phase of this oscillatory motion, and which, therefore, are moving precisely together, as it were, neck and neck, is a wave-length, as just defined. Now, while the tremor, which constitutes the luminous energy, is transmitted along the line of the ray with the velocity of 186,000 miles a second, the amplitude of the oscillations themselves

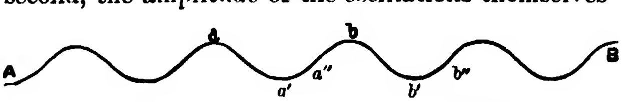

Fig. 1.—Diagram illustrating the Transmission of Light in Wave-motions.

is exceedingly small, and the waves are, on an average, only about one fifty-thousandth of an inch in length.

We say on the average, because within certain limits the wave-lengths are variable. On any one line of motion the waves have absolutely the same

* See also "Science for All," Vol. I., p. 363.

length, and this length never alters, however far the light travels on that path. But radiating from the same luminous source, and closely associated with this line of motion (which we have isolated in imagination for the purpose of illustration), there are an infinite number of similar lines on which the waves may have every possible gradation of length between the limits just referred to, and this difference of wave-length causes the effects of colour.

In thinking about this subject it is essential to keep clearly in view the distinction between the transmission of luminous energy along a ray of light, and the tremors or oscillations which are thus transmitted. The waves which these tremors form, differ, as we have just seen, in length, but whatever their length, they are transmitted along the line of motion with the same invariable velocity of one hundred and eighty-six thousand miles a second. Hence it is that the shorter the waves, the greater is

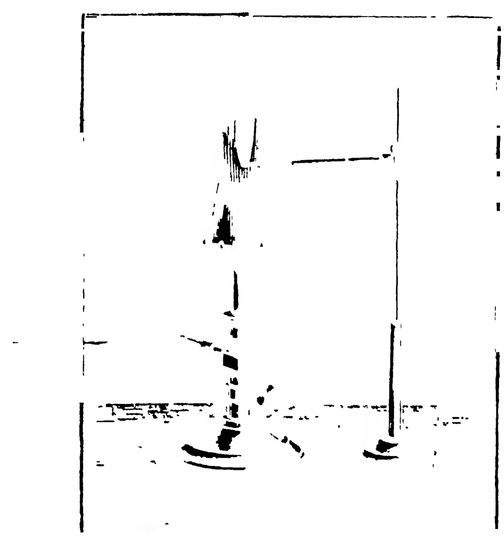

Fig. 2.—Experiment of producing a Light which emits Rays of only one colour.

the number of them that break on the retina of the eye in a second, and, so far as we have been able to analyse the phenomena, it is the frequency of these impulses which determines the sensation of colour.

It is easy by chemical means to produce a light which emits rays of only one colour (Fig. 2). If, for example, we melt a few grains of common salt to a bead on a loop of platinum wire, and hold the bead in the non-luminous flame of a Bunsen gas lamp, the vapour of the salt made incandescent by the flame gives out a pure yellow light. A salt of lithium treated in the same way yields a pure red light, and a salt of thallium a pure green light. Of such a light (monochromatic, as we call it) all the rays have the same wave

length, and such rays represent the simplest form of luminous energy. The quality of such a light cannot be altered by coloured objects or coloured media of any kind, and all bodies seen by it have uniformly its peculiar colour, varying only in brightness in proportion as they reflect or absorb the monochromatic rays. The light from a luminous gas flame, on the other hand, contains not only the same red, yellow, and green rays emitted by the artificial sources just mentioned, but also rays capable of producing an infinite number of other tints, and the confused sensation, which the combined impression produces, is what we call white light. The colour-giving power of such light is due to the fact that it contains within itself all the colour-giving rays. The leaf looks green, because it absorbs the different-coloured rays of the sunlight unequally, so that the reflected beam has an excess of green rays, and the coloured beams that filter through the painted windows of a church consist of the rays left after the pigments in the glass have exerted their selective absorption on the white light that falls on the outside. Natural colours, it must be remembered, are the result of the blending of many simple tints, and therefore differ essentially from the colour of monochromatic light. The eye, however, has not in all cases the power of distinguishing between a simple and a compound colour, and we must not confound the two effects, because the impression produced on the eye is the same. A monochromatic light can always be recognised by the dead uniformity of colour to which it reduces everything it illuminates. It can also be recognised in another way.

It is well-known that, while a glass prism bends a beam of light from its rectilinear path, it bends the different-coloured rays to a slightly different extent, sufficiently to spread them out like the sticks of a fan, thus producing a phenomenon called the solar spectrum. The best way of exhibiting this effect is illustrated by Fig. 3. By means of a lantern the narrow slit B is brilliantly illuminated at first, let us assume, with monochromatic light. The lens D, placed opposite to this slit, forms an image of the slit on the opposite screen. If now we place a prism E in the path of the light, and in the position shown in the figure, the beam is bent, and the image is thrown to the right as we face the screen. If we pass the beam through a second prism (E′) it is bent still more, and the image of the slit is further displaced to the right, and by adding prism after prism we can readily bend the lights around a complete circle, as shown in Fig. 4. The amount of bending by each prism depends on the refracting power of the glass, on the front angle of the prism (the refracting angle as it is called), and also on the position of the prism with reference to the beam. When the prism is so placed that the beam enters and leaves it at the same angle, the rays are bent the least, and this, which is called the position of minimum deviation, gives the

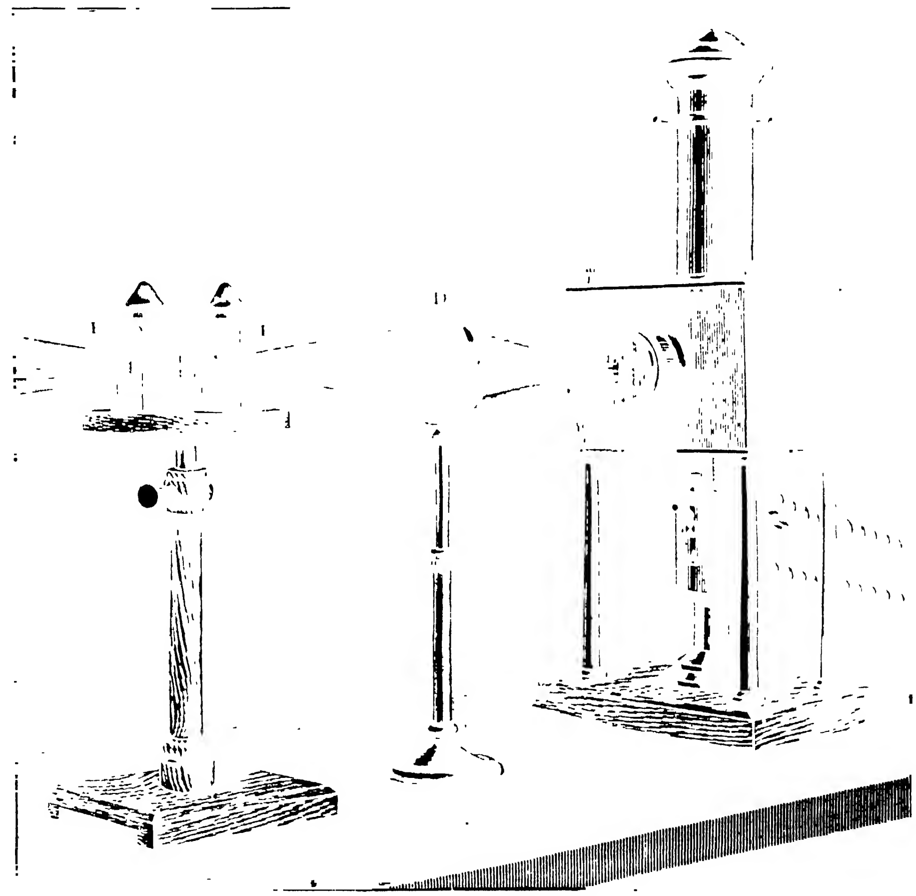

Fig. 3.—Illustrating the production of a Prismatic Spectrum.

best effects. The amount of bending also depends in part on the quality of the light, and if the three kinds of monochromatic lights described above are used in succession, it will be found that the red rays are bent the least, the green rays the most, and the yellow to an intermediate extent. With each we shall obtain an image of the slit, but in a somewhat different position on the screen, and if, as we readily can, we illuminate the slit with

Fig. 4.—Bending Light around in a complete Circle.

the three coloured lights at once, we shall see on the screen the three images at the same time, all parallel to each other, and each in the same position that it held when alone. If now we use a brilliant white light, that of an electrical lamp, for example, we shall have not only three, but an infinite number of such images overlapping each other, forming that band of blending colours represented by the solar spectrum.

A class of instruments called spectroscopes, or spectrometers, gives to the single observer a far more convenient and more delicate mode of viewing these beautiful phenomena. In these instruments one of the tubes is a simple telescope, such as is used for viewing distant objects. The other tube is called the collimator, and has at one end an object glass just like that of the telescope, while at the other end a slit (which may be broadened or narrowed by a screw) is placed exactly at the principal focus of the object lens. By means of a small prism, light from one side may be reflected through the upper half of the slit, while a light in front shines directly into the lower half. In this way the spectra formed by two sources of light may be superimposed and compared. The optical combination is such that if the telescope is placed opposite to, and in line with, the collimator, we shall see, on looking in at the eye-glass, a distinct image of the slit. If now we interpose between the two a series of prisms, and place the telescope in such a position as to receive the bent rays, we shall still see a single image whenever the slit is illuminated by monochromatic light, or several images, side by side, if the slit is illuminated by several monochromatic lights at once, and, when the slit is illuminated by white light, the spectrum band just described. A spectrometer differs from a spectroscope only in this, that the plate around which the telescope moves is accurately divided with degrees and provided with such adjustments, that, after the prisms have been placed at the angle of minimum deviation, the angle between the incident and refracted rays can be accurately measured.

As has been shown, the band of blending colour we call the spectrum is made up of an infinite number of definite images of an illuminated slit, placed side by side and overlapping each other. Each of these images is formed by monochromatic rays, and corresponds to the definite wave-lengths of the luminous pulsations which travel along the lines of these rays. In the unbroken spectrum obtained with the light from a gas-lamp, or an electric light, there is nothing to mark the position of the several images of which the spectrum is made up. But

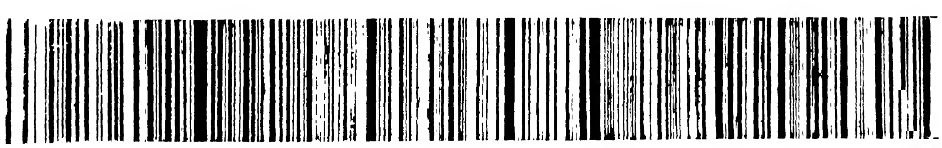

Fig. 5.—Rutherford's Photograph of the Blue Portion of the Spectrum.

the solar spectrum is crossed by a vast multitude of dark lines, which mark these positions with great definiteness. An idea may be formed of the great multitude of these lines from Fig. 5, which is a copy of a photograph of the blue portion of the spectrum made by Mr. Lewis M. Rutherford, of New York. These lines were first mapped by Fraunhofer, of Munich (in 1814 and 1815), and he designated the more prominent of them by the letters of the alphabet. It is not our province to discuss the significance of the dark lines of the solar spectrum, or the wonderful conclusions to

which the study of this subject has led. They are important in this connection only as marking the position of certain definite images of the slit, which correspond to definite monochromatic rays, and therefore to definite wave-lengths. In the following table we give the wave-lengths corresponding to the most prominent dark lines in each of the seven colours of the spectrum usually distinguished.

Dimensions of Light-Waves.

Colours.	Ray.	Number of waves in one inch.
Red	A	33,417
Orange	C	38,708
Yellow	D_1	43,131
Green	E	48,205
Blue	F	52,255
Indigo	G	58,971
Violet	H_1	64,011

There is no reason for specialising the monochromatic rays which we have selected in this table as illustrations of the dimensions of luminous waves, except that their absence is so definitely marked in the solar spectrum. The wave-lengths corresponding to many hundreds of the other dark lines have been measured with equal accuracy, and there is every possible gradation between the extremes. We recognise no inherent difference between rays of different colours, except that of wave-length, and the difference of wave-length between two red rays may be as great as between a red ray and a yellow ray. Colour is a purely subjective phenomenon depending on the relations of light to our own organism; and although we have collected a large number of facts in regard to the subject, we are still at loss to account for those qualities of colour which we distinguish by the familiar names, red, orange, yellow, green, blue, indigo, and violet. These were the divisions of the spectrum marked out by Newton,* but there is a gradual blending as we pass from one end to the other, and it is doubtful, at least, whether all the seven names represent essentially distinct qualities. We do know, however, that there are as many gradations of monochromatic rays as there are gradations of tints on the line of the spectrum, and that these tints are simple and unchangeable. Still, as we have said, the same luminous impression may be produced by a compound colour as by one of these simple tints.

If with a graduated scale before you, on which an inch is divided into one hundred parts, you strive to realise how small a distance the one five-hundredth of one of these minute divisions must be, you will begin to appreciate the delicacy of the measures which are recorded in our table. When first presented to those unfamiliar with the subject, these values almost always appear unreal, if not absurd, and it is therefore important to describe briefly how these minute distances are measured, in order that the reader may see that they are legitimate results of science, and be willing to accept them as a basis for the approximate measurement of still smaller magnitudes; for in the same way that the velocity of light gives us a standard for estimating the stellar distances, so these wave-lengths will help us to estimate molecular magnitudes.

In measuring wave-lengths, we use a scale ruled on glass, or on a polished plate of speculum metal and such perfection has been obtained in the construction of dividing engines for ruling these scales, that it is possible to rule lines on a plate of glass so close together that the bands of fine lines thus obtained cannot be resolved even by the most powerful microscope. Nobert, a German optician, ruled bands containing about 224,000 lines to an inch, and he regularly made plates with bands consisting of from about 11,000 to 112,000 lines to the inch. These bands are numbered from the first to the nineteenth, and are used for microscopic test. The appearance of the nineteenth band, as photographed with one of Tollis's objectives, is shown in Fig. 6.

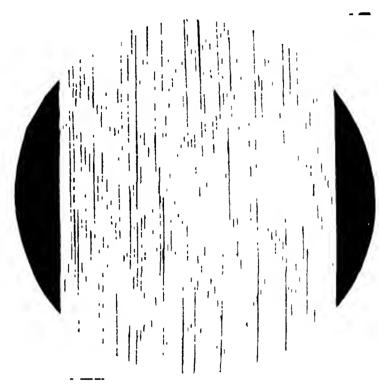

Fig. 6.—The Nineteenth Band of one of Nobert's Plates.

For measuring wave-lengths we do not require a scale ruled as closely as this, but we do require that it should be ruled with perfect accuracy, so that the spaces between the divisions should all be equal within a very small fraction of each single subdivision. This important condition fulfilled, the closer the lines are together the better. Mr. Rutherford has devised, and had constructed, a dividing-engine which rules about seventeen thousand lines to the inch with wonderful uniformity and equality of spacing. With this machine his assistant regularly rules on prepared plates of metal or glass, lines of the fineness and uniformity we have named, which are two inches long, and cover a space two inches wide.

Knowing, now, the value of our scale—that is,

* See also "Iridescent Glass:" "Science for All," Vol. I., p. 364.

the distance apart of the equal divisions—we are evidently prepared to measure the minutest objects which can be seen with a microscope; but how can we apply this scale to such an intangible and invisible magnitude as a wave of light? A feature of light, characteristic of wave-motion, gives us at once the means. Every one is familiar with the fact that if two waves of water meet, so that the crest of one coincides with the crest of the other, the energy of one is added to the energy of the other, and a wave of greatly increased dimensions rolls forward. But if the crest of one falls over the trough of the other, the two sets of waves, if of equal magnitude, neutralise each other, and the motion stops then and there. A similar result is caused by the concurrence, under certain conditions, of waves of light, and the effects thus resulting are well known in optics under the name of "interference phenomena." The fringes (consisting of alternate dark and light bands) which are seen when a brilliant monochromatic light is viewed through a narrow crack close to the eye, is one of the simplest examples of this class of phenomena. The light bands are formed by the interference of rays coming from the same source, but following slightly different paths, so that one gains on the other a whole, or some multiple of a whole wave-length; while the dark bands are formed by the interference of waves whose paths differ from each other by a half-wave-length, or some odd multiple of a half-wave-length. In the first case evidently a crest falls over a crest, and enhances the luminous effect, while in the last case the crest of one line of waves meets the depression of another, and the light-giving power of both comes to an end.

In the interference phenomena we have referred to, we notice a succession of several alternate light and dark bands, which we designate as the first, second, and third, counting from the medium line, which is usually very prominent; and if our inference in regard to the cause of the phenomena is correct, it is obvious that the first bright band corresponds to a difference of path of one wave-length of the monochromatic light we are using; and it is further evident that if we can measure this difference of path we have at once the length of a wave of this particular light. Now, the scale we have described enables us to measure the difference of path in the following remarkable way.

We place the ruled plate O (Fig. 7) at the centre of the graduated circle of the spectrometer, with the ruled surface opposite to the object-glass of the collimator, C, and adjust the instrument so that while the plate is at right angles to the axis of the collimator the rulings are perpendicular to the graduated circle, and also parallel to the slit of the collimator. Assuming now that the slit is illuminated by monochromatic light—that of a lithium flame, for example—we shall find, on bringing the telescope into the position T_rO, so that it makes (with the collimator) a definite angle T_rOC measured on the graduated arc, that we see a distinct image of the slit. If next we move the telescope to the right, we shall find a second image of the slit at the position $T_{r'}O$, and a third in the position $T_{r''}O$, and in like manner a fourth, a fifth,

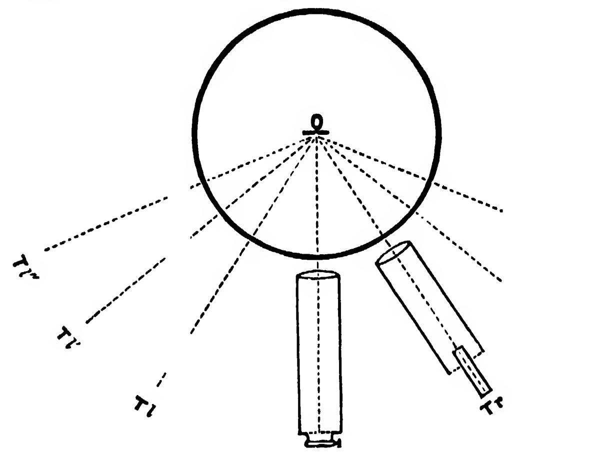

Fig. 7.—Diagram illustrating Method of calculating Wave-lengths.

&c., as we move farther round; but each successive image appears fainter than the last, until no longer distinguishable. If, now, we swing the telescope round on to the other side of the collimator, we shall find the same images repeated in the positions T_lO, $T_{l'}O$, $T_{l''}O$, &c., positions which subtend with OC the same angles as before; and the angle of the telescope in each of these positions with the collimator can be most accurately found by measuring the angle between the two corresponding positions on opposite sides—for example, T_r O T_l and halving it. Having measured these angles, and knowing the value of our ruled scale, we have all the data required for calculating the wave-length of the lithium light we are using.

After what has been said it will be obvious that we are here dealing with an interference phenomenon similar to those just mentioned, and that the positions of the images of the slit are those in which rays meet, whose differences of path are equal to one, two, three, and four wave-lengths respectively. The rays emanating from each point of the slit are rendered parallel by the lens of the

collimator, and strike the ruled surface under the same relations, and are reflected or dispersed by the zig-zag surface laterally in all directions, and the directions in which the images of the slit are seen are those in which the beam consists of rays reflected from corresponding points in the several grooves, so that the difference of path of each neighbouring pair is one, two, or more wave-lengths, as the case may be, and, as we should anticipate, the interference of the rays, under these circumstances, increases the luminous effect. In the simpler phases of the interference of light the bright bands gradually fade into the neighbouring dark bands; that is, between the positions of brightest and least illumination there are points of partial interference, and therefore of partial obscuration, but the peculiarity of the phenomenon here exhibited is, that all the light is concentrated in a few images, all the rays which are reflected in other directions mutually destroying each other. This striking peculiarity can be shown to result from the great number of grooves ruled on our plate; but it would require a very long digression from the main line of our argument to make this point clear, and the reader who is sufficiently interested to search out the whole matter will find the subject fully explained in works on the higher optics.

Dwelling now solely on the fact that the directions we have pointed out correspond to a difference of path of one, two, or more wave-lengths respectively, let us see how we can deduce the value of the wave-lengths from the data we have observed.

In Fig. 8 let O and O′ be corresponding points in two adjacent grooves of our ruled plate, which are distant from each other by a known fraction, say the one-seventeen-thousandth of an inch. Let CO and C′O′ be parallel rays from a given point of the slit which strikes at O and O′ under precisely the same conditions. These rays are reflected, forming OT and OT′, which, as we will assume, are rays of the beam that form the first image of the slit. The angle TOC or T′O′C′ has been measured, for it is the same as the angle T_rOC, or one-half the angle T_rOT_l of Fig. 7.

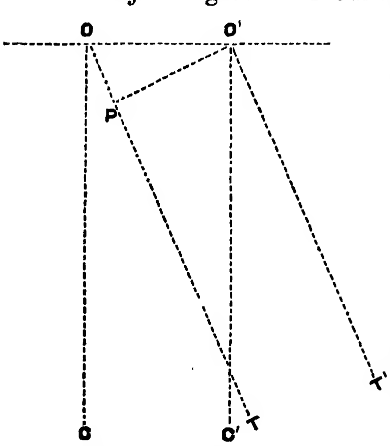

Fig. 8.—The Mode of Deducing the Value of Wave-lengths.

These data given, it is obvious that the reflected rays OT and OT′—which coalesce, so far as the eye can distinguish—must have the difference of path OP, and the same will be true of every other pair of rays reflected under like conditions. Further, PO, according to our assumption, is the length of a wave of the monochromatic light we are using, and since in the right-angled triangle POO′ we have given the side OO′ and the angle OO′P, or its equal TOC, we can easily calculate OP, the wave-length, for according to trigonometry

$$OP = OO' \sin OO'P = OO' \sin TOC,$$

or representing, as usual, the wave-length OP by λ, and the width of the divisions of our plate OO′ by b, and the measured angle by δ_1, we can write the formula for calculating wave-lengths—

$$\lambda = b \sin \delta_1 = \tfrac{1}{2} b \sin \delta_2 = \tfrac{1}{3} b \sin \delta_3 = \&c.$$

In the second and third terms δ_2 and δ_3 stand for the angles subtended by the second and third images. In these cases OP is equal to two or three wave-lengths, that is $OP = 2\lambda$, or $OP = 3\lambda$, and the values given are at once deduced. Thus by measuring the different angles we can calculate the same wave-length from as many different data, and the fact that the several results thus obtained never differ from each other more than can be accounted for by the errors of observation or of construction, is a strong confirmation of the correctness of the theory on which our measurement rests.

It may be noticed, lest the obvious inference should not be drawn, that if instead of using the lithium light in our experiment we used other monochromatic lights, we should see the images of the slit in different positions, depending on the different wave-lengths, and if we used white light we should have at once the images corresponding to all the possible wave-lengths; that is, we should have a continuous spectrum, and as we moved the telescope around the graduated arc we should see one spectrum after another, corresponding to the successive monochromatic images; but like the monochromatic images, these spectra rapidly grow fainter, and those of the higher orders, as they are called, overlap each other. These ruled plates give us, therefore, another means of producing a luminous spectrum, and the plates have the advantage of the prism in that the several colours of the spectra produced by them are distributed in proportion to the wave-lengths of the corresponding rays, which is far from being the case in the spectra formed with prisms.

A MANURE HEAP.

By David Houston, F.L.S.,

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IT has been explained in previous papers* how living plants remove certain constituents of air and soil to enable them under the influence of sunlight to manufacture different organic compounds, as materials for the construction of various tissues which build up the plant's body. The plant, it will be remembered, can only make use of those materials in the soil which exist there in a soluble state, and although these substances are present in very small comparative proportions, yet under natural conditions no difficulties are experienced by successive generations of plants in obtaining sufficient mineral food for all physiological purposes, as when one generation dies it decays on the spot where it has just ceased to live, and slowly returns to the soil the very selfsame inorganic ingredients which were removed from it during the period of growth. In the practice of agriculture, however, the farmer removes most of his crops from the soil, and thus robs the land of much of its valuable plant food; indeed, as is well known, he may render his land absolutely barren by continuing to grow and remove successive crops of the same kind, unless he gives back to the soil similar chemical substances as the particular crop he has grown has removed. One of the purposes for which the crop is carried away from the soil is to feed the farm stock, as the business of a farmer is not only to produce grain and roots, but flesh and animal fat as well. Much of the vegetable matter eaten by animals is rendered soluble by the special actions it is subjected to in the digestive organs; it is then absorbed and used for the purposes of building up the various tissues of the animal body, and maintaining the necessary degree of bodily heat; but insoluble portions which have resisted absorption are subsequently rejected as useless or excrementitious matter. A living animal, too, is constantly suffering loss of muscle, nerve, and other tissue, and these waste materials in all healthy individuals rapidly undergo important chemical changes in the body, so as to reduce them to a state in which they may be easily expelled by the lungs or removed in solution in water by the kidneys.

Bearing in mind these facts, it will be readily seen that the bodies of plants and the various excrementitious matters of animals, contain the identical chemical elements, the removal of which from the soil caused its partial or complete exhaustion; and it will be further seen, that farmyard manure, consisting as it principally does, of organic matter derived from plants and animals, composed mainly of straw and other litter intermixed with solid and liquid animal excrements, contains all the valuable fertilising materials the addition of which to an exhausted soil fully restores to it its original fertility and power to produce good farm crops.

It now seems necessary to inquire as to what all these different indispensable materials are, that must be ever present in sufficient abundance, and in an available form, in all fertile soils. This knowledge may be gained in several ways; but a complete analysis of the plant will perhaps best show what elements are required for the proper construction of its tissues, and the continuance of a healthy growth. Plants, like all other organised beings, are, of course, more or less saturated with water (OH_2). If removed from the soil and dried at a temperature of 100° C. (212° F.), they suffer material loss, herbaceous plants generally losing from sixty to eighty per cent. of their weight. The bulk of the dry solid matter that remains, consists of organic substances of rather complex chemical composition. Giving the elements merely, the cellulose, woody fibre, starch, sugar, fats, and oils, are composed of carbon, oxygen, and hydrogen, while protoplasm and the albuminoids (fibrine, legumin, &c.) are made up of these three elements with nitrogen and sulphur in addition. If the dry, solid matter be now completely burned, this organic matter will be resolved into volatile products—principally "carbonic acid gas" or carbon dioxide (CO_2), water and ammonia (NH_3)—leaving a white powdery ash or non-volatile residuum of mineral matter. There are certain constant elementary ingredients in all plant ash, although the respective amounts of each ingredient vary in different plants, and even in different parts of the same plant. There are other elements which are only required by particular plants, or have accidentally found their way into the plant. The elements potassium, calcium, magnesium, iron, phosphorus, sulphur, and

* "Science for All," Vol. I., pp. 19, 96, 294.

chlorine are absolutely essential for plant nutrition, and are therefore constant ash constituents. It appears that in addition to giving a certain stability to the plant's body, these essential mineral substances perform individually several important physiological functions in the vegetal economy. For example, unless iron is present it seems that no chlorophyll or green colouring matter can be formed; but even in presence of iron, yet in the absence of potassium, no manufacture of starch can take place, while phosphorus, it is said, is in some way or other associated with the albuminoids. In addition to these, which are so essential, other elements, such as sodium, lithium, manganese, silicon, iodine, and bromine, and in rare cases copper, zinc, cobalt, nickel, strontium, and barium are found in the plant ash. The following table will show the comparative compositions of three common agricultural plants :—

	Wheat-Straw.	Turnips.	Clover.
Water in 100 parts	14·23	90·43	80·64
Albuminoids „	1·79	1·14	3·60
Starch, &c. „	31·06	5·45	13·79
Woody fibre „	45·45	2·34	
Mineral matter (ash)	7·47	·62	1·97

The elements carbon, hydrogen, and oxygen are plentifully supplied to the plant; the first, making up quite half its dry weight, being derived from the carbon dioxide of the air, and therefore inexhaustible in supply, the two latter being, principally at least, derived from water. Nitrogen and sulphur, the two remaining constituents of the organic matter, are obtained from the soil; nitrates and compounds of ammonia supplying the nitrogen; and soluble sulphates supplying the sulphur.

Turning now to the non-volatile, or ash constituents, all of which are of course derived from the soil, we find that these in all cases exist in chemical combination with other elements forming soluble or insoluble inorganic salts. These substances, generally by simple diffusion only, are absorbed by the plant in solution in water; sometimes, perhaps, in particular cases, they may be slightly dissolved by the organic acids contained in the cells of the roots, and then absorbed as organic salts, whilst, probably, in other cases they may owe their entrance to the very intimate connection existing between the particles of the soil and the multitudes of absorbing hairs of the root. The accompanying illustration (Fig. 1) will show how tenaciously the particles of soil cling to the root-hairs, even after the earth has been allowed to dry, and the young plant then roughly shaken. Potassium, present perhaps to the extent of almost three per cent. of potash, in rich, loamy soils, may be absorbed in the form of potassic chloride, nitrate, or sulphate—compounds, one or other or all of which have been found in

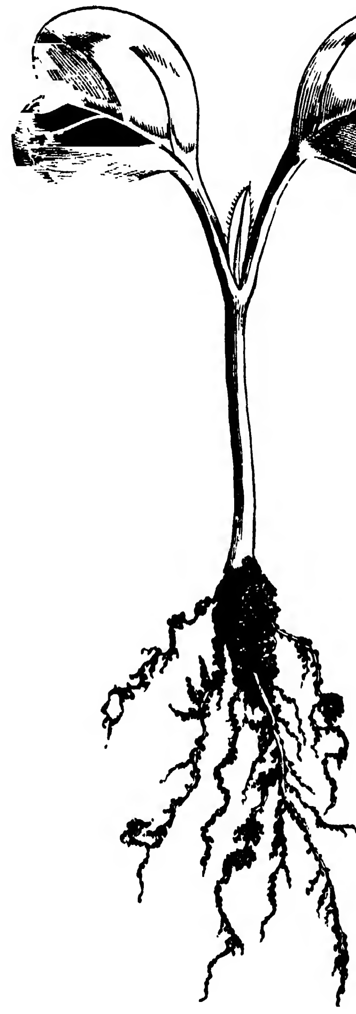

Fig. 1.—Young Turnip Plant 9 days since date of Sowing, showing how the Root-hairs are closely covered with firmly-adhering Particles of Earth. (*Enlarged about 2½ times.*)

samples of fertile soils. Calcium exists in the soil as chalk, gypsum, and phosphate of lime—substances which, although almost insoluble (especially the first and last) in pure water, are readily dissolved in water containing carbon dioxide in solution. Magnesium is probably either supplied from the sulphate of magnesia (better known as Epsom salts), or magnesium carbonate (magnesia alba of the shops). The average proportion of this element in loams is about one per cent. of its oxide, magnesia. The hardness of water, it will be remembered (Vol. II.,

p. 70), is due to the presence of some compound or compounds of calcium or magnesium. Iron is generally abundant in soils in the form of oxides, the proportion being often as much as five or six per cent. Phosphorus—present as phosphates of aluminum, iron, and calcium—exists in very small proportions even in good soils, ·2 per cent. of total phosphates being perhaps a fair average.

We have now seen that, excepting carbon, hydrogen, and oxygen, the plant is dependent upon the soil for all its other food constituents; hence the great importance of having suitable soils for the growth of cultivated crops.

Although the percentage of ash is very small, yet the total amount of mineral matter annually removed by growing crops is somewhat considerable, when we remember that plants require the compounds containing these elements presented to them in a soluble form, and also bear in mind that the percentage of soluble matter is very small even in a most fertile soil. There are recorded analyses giving the percentage of substances soluble in water as ·2319 in one case of a good soil, and ·1191 in another case; that is to say, about three tons per acre of a depth of ten inches, reckoned as an average depth for roots. This weight represents the total amount of food existing in a state fit to be taken up at any given time by plants. There are substances similar to these already available materials existing in soils which, although not yet quite in a soluble condition, will slowly become so under the weathering influences of the air and other natural forces. These latent plant-food materials, or substances soluble in weak acids, exist in percentages varying in fertile soils from 6 to 8. A crop of wheat, according to Playfair, will remove 175 lbs. of mineral matter from an acre of land, while a crop of turnips will remove 640 lbs. from the same area. This will explain the exhausting influence of all growing crops. Further, as has been already stated, different crops do not remove equivalent amounts of the same substances. While wheat, in the above example, removes as much potassium as is represented by 25 lbs. of potash, and as much phosphorus as is represented by 20 lbs. of phosphoric acid, turnips will remove 200 lbs. of potash and about 59 lbs. of phosphoric acid. All the substances stated to be essential for plant growth must be present in the soil, not only in a perfectly soluble condition, but each constituent must exist there in sufficient quantity for the full development of the plant: the absence of one, or even the mere paucity of one, is a sufficient cause for barrenness.

It is from plants, of course, that all farm stock derive their food. A chemical analysis of a horse, cow, sheep, or pig will give a result strikingly similar to that of a wheat, turnip, or clover plant. The substances making up the body of an animal may, as in the case of the plant, be roughly divided into water, organic matter, and ash. During the life of the animal certain waste of tissue is going on, and the waste products are eliminated from the blood by specially-constructed glands, from whence they are ejected from the body. These waste products, containing, as they do, worn-away portions of the animal tissue, contain the same chemical elements as were removed from the soil by the plants. Taking the urine of the cow as a typical example of this kind of matter, we find that its composition is as follows:—

	In 1,000 parts.
Water	920
Organic matter	60
Inorganic matter (ash)	20

The organic matter contains urea and uric acid, important manural substances yielding upon decomposition somewhere about one per cent. of ammonia-forming nitrogen. The inorganic constituents consist of common salt (sodium chloride), sulphuric and phosphoric acids, with salts of potash, soda, lime, and magnesia. As an example of solid excrement, that of the cow may be fairly taken as a type. Its composition in 1,000 parts is as follows:—

Water	840
Organic matter, being insoluble portions of food	136
Inorganic substances	25

It may be explained that although the actual quantity of organic matter in 1,000 parts is much greater in this case than in that of urine, yet the smaller proportion of organic matter in the latter-named substance contains between two and three times more nitrogen capable of forming ammonia than the bulkier proportion of the same matter in the solid excreta.

Farmyard manure, being a mixture of solid and liquid excreta derived from various animals, and intermingled with the straw of various plants, it will be readily understood, from what has now been said, that it contains all the materials necessary for the restoration of the fertility of soils exhausted by continual growth and removal of crops. But again, remembering once more that plants must have their food presented to them in

a soluble form, and knowing that the solid materials in fresh manure are to a large extent insoluble in water, it will be readily seen that the substance of the heap must sooner or later undergo such changes as will result in the conversion of a large proportion of its insoluble matter to a soluble condition before it is in a fit state for the immediate use of the plant. The following table, founded on analyses made by Dr. Voelcker, showing the composition of fresh (about 14 days old) farmyard manure, composed of the droppings of the horse, cow, and pig, will illustrate this point:—

	In 100 parts
Water	66·17
Soluble organic matter containing ·149 per cent. of nitrogen, capable of forming ·181 per cent. of ammonia	2·48
Insoluble organic matter containing ·494 per cent. of nitrogen, capable of forming ·599 per cent. of ammonia	25·76
Soluble inorganic matter containing silica, phosphate of lime, lime, magnesia, potash, soda, chloride of sodium, sulphuric acid, and carbonic acid	1·54
Insoluble inorganic matter containing all the above inorganic ingredients with oxide of iron and alumina in addition	4·54

It may be added that the whole manure contained ·034 per cent. of ammonia in a free state, while an additional ·088 per cent. existed in combination as salts.

When dead organic matter is kept moist and freely exposed to the air within certain ranges of temperature, it undergoes a series of remarkable changes, whereby the complex compounds are broken up into simpler bodies, the final result being the complete decomposition of the original matter. The putrefaction of a manure heap is brought about, as all putrefactions are, by the growth of certain microscopic fungi belonging to the group named *Schizomycetes* by botanists. These extremely minute unicellular organisms, as has been seen,* are floating about in the air, settling in all situations, and multiplying at an astonishing rate wherever they find a suitable habitat. Like other plants, they require carbon, hydrogen, oxygen, and nitrogen, as also inorganic matter, for their sustenance. Unlike green plants, however, they are dependent for food upon already organised matter; this provided, they set to work decomposing the complex chemical organic structures, using such portions as they require for food, and liberating solid, liquid, and gaseous factors, some of which are of course volatile, the organisms in the meantime multiplying with enormous rapidity. The ordinary conditions favourable to the growth of these bacteria, and therefore favourable to quick decay—in addition to having a dead nitrogenous organic body as a feeding-ground—are the presence of a moderate supply of moisture, warmth above the freezing-point and below the boiling-point of water, and an abundance of fresh air. The principal products of putrefaction are water, carbon dioxide, ammonia and ammoniacal gaseous compounds, sulphuretted hydrogen, and certain organic acids.

* "Science for All," Vol. IV., pp. 317–319, Figs. 1, 2, 3.

That these changes are really brought about by the growth of these organisms may be readily proved by a series of easily-performed experiments similar to those already described (Vol. IV., p. 317). Half fill three flasks with a well-strained infusion of hay, cabbage, beef, or any other vegetable or animal nitrogenous substance. Boil the infusion in two of the flasks, and, while the steam is issuing from the neck, stop up the mouth of one of the flasks with a plug of cotton wool; then place the three vessels aside. As a temperature above the boiling-point of water generally kills all forms of life, so, by boiling the infusion, not only are all germs in the liquid destroyed, but all organisms in any other part of the flask as well. Upon examining the contents of the flasks after the lapse of three or four days, the liquid in both the two open vessels will be found to stink, while the infusion in the flask plugged with the cotton wool will be found as sweet and fresh as when first put in. Here the cotton wool so completely filtered the air that even the minute bacterian organisms were excluded, and therefore preserved the infusion from their attacks. If the plug is allowed to remain unmoved the infusion may be kept fresh and unaltered for years, while, on the other hand, if it is at any time removed, speedy putrefaction of the liquid will be the inevitable result. A drop of this putrid infusion, examined under a high power of the microscope, will be found to be swarming with forms of life such as those figured in Vol. IV., pp. 317-319.

As oxygen is required by the bacteria during these changes for purposes of oxidation, and, moreover, as the action of oxidation invariably produces heat, so during the decomposition (or fermentation, as it is often called) of the materials in the manure heap the temperature rises in proportion to the rapidity of the decay. All kinds of excreta do not decay with the same quickness: if we compare horse with cow manure, it will be found that the

former decomposes rapidly, and is therefore said to be "hot," while the latter slowly decomposes, and is known among farmers as a "cold dung." Under proper management, the manure heap is kept in such a condition, and the rate of decomposition is so regulated, that there is only very slight loss of any of the valuable products of decay. Vapour of water, carbon dioxide, and other volatile matters may and do escape; but ammonia, the most valuable constituent, is retained, being fixed by certain organic acids generated during the process of decay, of which humic and ulmic acids may be taken as types. With these two acids the ammonia unites to form humate and ulmate of ammonia, substances which are easily soluble in water.

If, either through neglect or ignorance, the heap is allowed to get too dry, then the progress of decay is partially arrested, and the before-mentioned organic acids are not formed; under such conditions the ammonia combines with the carbon dioxide, forming carbonate of ammonia, which, being volatile, escapes, thus robbing the manure of its most valuable fertiliser. On the other hand, if the heap is allowed to become so wet that the water drains away, then the ammonia, now in the form of ulmate and humate of ammonia, is carried off in the well-known black streams too often seen flowing from heaps of farmyard manure. As the decomposition is going on, the heap is gradually becoming darker-coloured, more compact, and materially reduced in weight, while at the same time the proportion of soluble substances is considerably increased. It has now reached that final stage when incorporation with the soil is highly desirable. Its immediate application will prevent serious loss; this is particularly true if the heap is kept uncovered, as it has been found that twelve months' exposure is sufficient to wash away or otherwise remove to the merest traces all the valuable fertilising substances in the heap.

We have, therefore, now seen that all plants require certain essential chemical elements to enable them to build up their tissues during their respective periods of growth; that these elements must be presented to them in particular forms and under certain conditions; that they require water at all times, which is usually supplied by rain and dew, while the food they require in greatest bulk (carbon) is most plentifully supplied by carbon dioxide, ever present in atmospheric air, but for their supply of nitrogen and all the essential (and non-essential) inorganic materials, they are wholly dependent upon the soil; that by growing plants upon and then removing the crops from off the soil, the farmer robs the land of all those materials taken up by the plant, and by a continuance in this practice, without giving equivalent amounts of *all* the substances so removed back to the soil, the land in time becomes thoroughly exhausted; that these losses may be best made up by the application

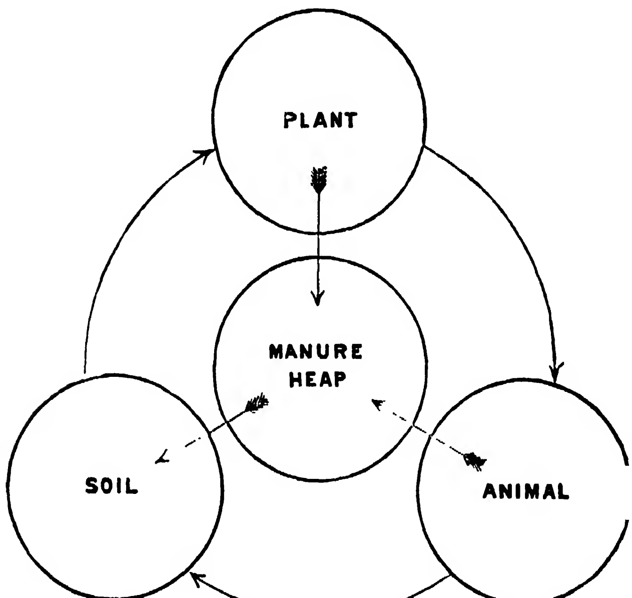

Fig. 2.—Diagram showing the Direct and Bye-paths that are and may be taken in the Perpetual Cyclic Movements of Mineral Matter.

of farmyard manure—a manure which in its fresh state is merely a collection of plant bodies, undigested vegetable matter, and animal waste products; that these, by subsequent decay, yield up to the soil the same or similar materials lost during the growth of the crops, presented in such a condition that they may be forthwith re-used for the purpose of again helping in the construction of plant tissue. Finally, we have also seen that there is a slow but nevertheless a perpetually-moving cyclic stream of inorganic matter flowing from the soil through the plant to the animal, and from thence back again to the soil; and that a manure heap may be compared to a central pool (Fig. 2), into which branching streamlets from both plant and animal sometimes flow, but only to again join the main stream at the soil, and move onwards with the broad current flowing in the direction of the plant.

WARREN DE LA RUE'S GREAT VOLTAIC BATTERY.

By Robert James Mann, M.D., F.R.C.S., F.R.A.S., etc.

THE chloride of silver battery, alluded to at the conclusion of a recent paper on the nature of voltaic electricity, was first described by its inventors, Dr. Warren De la Rue and Dr. Hugh Müller, in 1867. One hundred cells were exhibited in operation at a meeting of the Royal Society held on the 7th of March of that year. It was contrived for the facility which it gave of bringing a very large number of cells into connected action, and in this particular it has marvellously answered the purpose for which it was designed, as on the 21st of January, in 1881, a battery of 14,400 cells was set to work at one of the evening meetings of the Royal Institution in London. This battery was constructed in the first instance for investigating the nature of the electrical discharge in highly rarefied media, and in the form in which it was exhibited upon this occasion, it is by far the largest voltaic battery that has ever been brought into action.

The chief peculiarity of the battery is that it is a solid substance—the chloride of silver—which furnishes the current of electricity in consequence of its slow and gradual decomposition. This solid electrolyte takes the place of the sulphate of copper employed in the Daniell's form of constant battery. It is used in connection with a rod of zinc, the two elements—the chloride of silver and the zinc—being immersed in a glass jar or cell containing a weak solution of chloride of ammonium, or chloride of sodium. The chloride of silver is quite insoluble in this liquid. When the connection between the two elements is not closed into a circuit, no action whatever takes place, but as soon as the circuit is closed, the zinc dissolves, and the chloride of silver parts slowly with its chlorine, and in doing so, is changed into the state of a porous mass of reduced silver, setting free a current of voltaic electricity so long as the decomposition is in progress. The battery has the very great recommendation that, although it dispenses with the porous jar, and the two different kinds of liquid, it is, nevertheless, remarkably constant and durable in its action, and although the silver element is costly in the first instance where a large battery is concerned, nearly the whole of the silver can be recovered after the exhaustion of the battery. Dr. De la Rue found that the actual loss of silver with good management does not necessarily amount to more than one and a half per cent. There are 200 grains of the chloride in each cell, which is worth about two shillings, including the cost of fusing it and casting it into the form in which it is employed. The cost of the silver employed in the large battery at the Royal Institution was about £1,440.

The cell of the battery consists of a flat-bottomed glass jar, a little more than one inch in diameter, and five and a half inches high. It is capable of holding about two ounces of solution, and is closed at the mouth by a plug or stopper of paraffin, which is perforated in two places to allow the passage of the zinc rod, and to permit the introduction of the liquid solution by means of a pipette and syringe formed of an india-rubber tube armed with a piece of glass tube drawn out to a point. The zinc element consists of a fragment of pure Belgian zinc wire, one-fifth of an inch in diameter, and two inches and a half long. The silver element is formed of a solid rod of fused chloride of silver, cast round a thin flat wire, or ribbon, of pure silver by pouring it in a molten state into a mould, in which the pure silver core has been previously fixed. The silver core projects through the bottom of the rod to establish a free contact with the liquid, and it is carried upwards between the glass neck of the jar and the paraffin bung or stopper. The chloride of silver rod is a little more than two inches long, and a quarter of an inch thick. It very much resembles a stick of lunar caustic, but when cold it is so tough that it does not readily crumble, and is yet so soft that it can be cut with a knife. When the cell is charged with its rods and liquid, the openings through the paraffin and the connection of the paraffin with the glass are all hermetically sealed by the application of a hot iron. The chloride of silver is protected from any chance contact with the zinc element deposited in the same cell by being surrounded with a cylindrical sheath of vegetable parchment, closed up into the form of a tube by means of stitches and cement at the outer edge. Connection is made between the chloride of silver rod in one cell and the zinc rod in the next by the flat silver wire which is carried up out of the glass jar between the glass and the paraffin stopper, and then inserted

into a hole drilled transversely into the top of the zinc rod, into which it is pressed and wedged firmly by means of a conical plug, as shown in the following sketch of the arrangements adopted in two contiguous cells (Fig. 1).

The glass jars are arranged in trays eighteen inches wide and four feet long, which, in the case

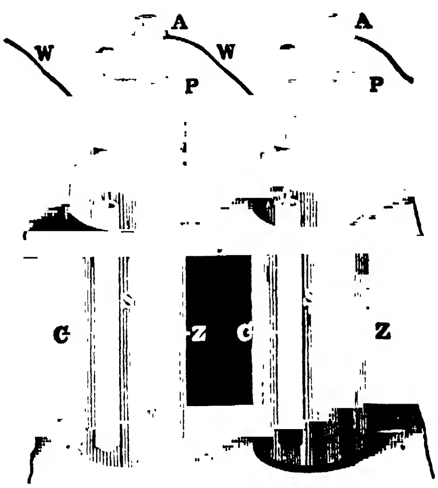

Fig. 1.—Two Cells of the Chloride of Zinc Battery, showing the Arrangements of their several parts.

Z, the Zinc Rod; C, the Chloride of Silver Rod, with W, its Core of Flat Silver Wire attached to the Zinc Rod of the next Cell, at A, by a hole and peg; P, the Stopper of Paraffin by which the mouth of the Glass Jar is closed, and S, the Solution of Chloride of Ammonium in which the Rods are immersed within the Cell.

of the large battery, were placod side by side upon shelves in cabinets. There were 200 jars upon each shelf, and 1,200 jars in each cabinet, so that twelve cabinets contained the whole battery. The construction of this battery at the Royal Institution was commenced in June, 1879, and it was completed in August, 1880. A fortnight was occupied in December in charging the cells with the solution of chloride of ammonium, containing about 190 grains of the salt to each pint of water. The series upon the several shelves and in the various cabinets were so coupled up by means of terminal screw-connections and switches, that any number of the trays could be joined up in circuit, or withdrawn from it, at the will of the operator. The action of the battery after it has been once built up is sustained for a long period of time; indeed, until all the chloride of silver is reduced to the state of metallic silver. In one tolerably large series of cells which Dr. De la Rue employed in his own laboratory, the electrical action was maintained for a period of three years without any perceptible diminution of power, a term which is obviously ample for the completion of a considerable range of experimental investigation.

The electro-motive force of each of these cells was found to be a trifle more than one volt—that is, an electric energy capable, when working through a pure copper wire one-sixteenth of an inch in diameter, and 129 yards long,* of decomposing the 0·00146 part of a grain of water in a second. The electro-motive force of the entire battery of 14,400 cells was 14,832 volts—that is, it was capable, when working through an ohm of resistance, of decomposing a little more than $21\frac{1}{2}$ grains of water each second.

Twenty cells of this very compact and handy battery proved to be sufficient to fire the ordinary blasting fuse. One hundred cells gave a brilliant arc, sustained between charcoal points, when drawn the sixteenth part of an inch asunder. Two hundred cells gave a luminous arc between charcoal points a quarter of an inch asunder. Eleven thousand cells gave a spark, sixty-two-hundredths of an inch long. And the 14,400 cells, which were coupled up together for the first time at the Royal Institution, gave a spark seven-tenths of an inch long, and which struck at once that distance from terminal to terminal without any previous establishment of contact and subsequent withdrawal.

The electro-motive power of the battery is, however, capable of being very materially increased by the expedient of attaching a condenser to its terminal wires when it is in action.† Several plates, however, have to be employed instead of a single pair, with their conducting-surfaces so arranged as to make the whole act like one enormous Leyden jar, with the opposite coatings separated by an intervening layer of non-conducting material. In one of Dr. De la Rue's condensers, plates of glass about a foot square were arranged in grooves side by side, with tin-foil attached to each surface, but not reaching to the margin of the glass, so that its insulation was in this way provided for. The connection of the coatings of tin-foil was then so managed that all the coatings on one side of the glass plates were brought into continuous metallic communication as one series; whilst all those on the opposite side formed in a similar way another series. This, however, may be most readily understood by a glance at the following figure, which is intended to represent, diagrammatically, the

* The resistance to an electrical current furnished by a copper wire one-sixteenth of an inch in diameter, and 129 yards long, is called, technically, an "ohm." A "volt" is an electro-motive force capable of making its way through an ohm of resistance, and of, at the same time, decomposing 0·00146 of a grain of water every second.

† "Science for All," Vol. V., p. 171.

connections of the opposite coatings of such a condenser (Fig. 2):—

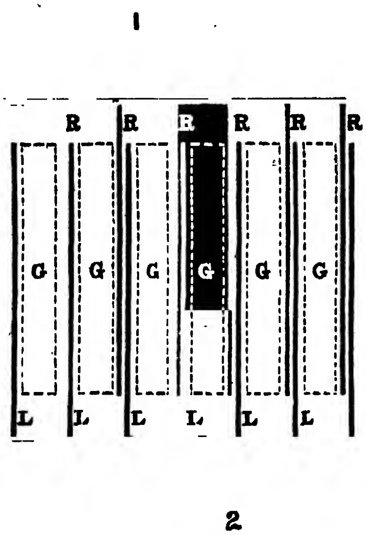

Fig. 2.—Showing Diagrammatically the arrangements of the Coatings of the large Condenser used in Dr. De la Rue's Experiments.

All the coatings on the left sides of the Plates of Glass (L) are connected Metallically with the Conducting Track (2); whilst all the coatings on the right side of the Plate (R) are connected Metallically with the Conducting Track (1); the dotted spaces (G) representing in Section the Position of the Insulating Plates of Glass.

One of the condensers employed by Dr. De la Rue contained metallic surfaces equal in extent to 6,485 large Leyden jars with 442 square inches of coating in each.* In using this condenser, the one series of coatings is placed in communication with one of the terminals of the voltaic battery, and the other series with the opposite terminal. The result, then, practically is, that each of the terminals acts with this large supplementary reservoir of inductively concentrated electrical force attached to its system of discharge. The coats of the condenser get charged up to a certain grade of active energy, and the current is then reinforced in its electro-motive or resistance-overcoming power, to the extent of the charge. Dr. De la Rue's intention was to exhibit the full power of the battery in connection with the large condenser at the Royal Institution, but it was found to be impossible to do this, because the plates of the condenser were immediately broken by the flashing of the discharge through the glass. Not more than 3,240 of the cells of the battery could be used with the condenser. With these, however, the discharge was strong enough to deflagrate two inches and a half of gold wire the eightieth part of an inch in diameter with a loud report, merely leaving a stain of metallic dust scattered upon the glass on which the wire had been stretched. It also sufficed to deflagrate twenty-nine inches of platinum wire the hundredth of an inch in diameter. The spark passed between the separated terminals of a discharger with a loud report. It was, nevertheless, apparent that the condenser could be fully charged with a current that would not suffice for the decomposition of more than the five-thousandth part of a grain of water. Dr. De la Rue calculated that in order to get an electrical flash equivalent to a discharge of lightning 63,366 inches, or one mile long, it would be necessary to have at command a battery 243 times more powerful than the one with 14,400 cells. This would be represented by about three millions and a half of cells. The electro-motive energy of the voltaic current is, however, capable of being still more increased by the instrumentality of the condenser when its coatings are arranged in a different way, so as to produce what is technically known as the cascade effect. This is done by coupling up the right and left coatings of the contiguous glass plates, instead of connecting all the right-hand and all the left-hand coatings together, and keeping each couple isolated from the rest. Each pair then acts inductively upon its neighbour very much in the same way as the successive cells in a voltaic battery act upon each other, but with a still more rapid augmentation of the energy, from increase in the number of plates. Twelve hundred voltaic cells, which only gave a spark the 0·00608 part of an inch long, gave a spark an inch long† when they were connected with twenty-five condensing-plates arranged in the form of a cascade. This particular experiment is principally important, because it suggests the idea that the great intensity of the lightning discharge may possibly be due to insulated plates of cloud being arranged in the air, so as to act like a cascade-condenser.

The power of the arrangement of artificial apparatus to augment the striking energy of an electrical discharge, however, becomes still more strikingly manifest when the performance of the great inductive coil of Dr. Spottiswoode, which was also exhibited at the Royal Institution, at a meeting held on the 13th of April, 1877, is contrasted with the action of Dr. De la Rue's chloride of silver battery, when reinforced with the condenser. In

* The largest condenser of this kind that has ever been constructed is one that is employed in connection with the Duplex process of transmission by the direct United States Cable Telegraph. There are in that instrument 100,000 square feet, or more than two acres of insulated metallic surface. That Leviathan of condensers is contained in seventy boxes two feet long, a foot and a half broad, and seven inches deep.

† That is one hundred and sixty-four times as long.

Dr. Spottiswoode's apparatus a coil of wire the one-hundredth of an inch in diameter, and 280 miles long, was inductively thrown into action by means of a primary coil of wire one-tenth of an inch in diameter, and 660 yards long, through which voltaic currents were circulated intermittingly from a small battery of Grove's cells. In this form of apparatus a current is only produced in the secondary coil at the instant when the circuit is opened and closed in the primary coil, and the intensity of the effect very largely depends upon the rapidity with which the opening and closing are produced. The mechanical arrangement, by which the requisite rapidity is secured, is the simple expedient of causing a brass wheel, scored by radial slits filled up with non-conducting ebonite, to revolve, so that when a flat platinum spring is caused to press upon the face of the wheel a current is passed every time it touches the brass surface, and is stopped every time the spring passes the non-conducting or obstructing band of ebonite. In Dr. Spottiswoode's own laboratory the wheel is driven by a small steam-engine, and interruptions in the current of the primary coil are produced from 700 to 2,500 times in a second. With this apparatus, used with a condenser of 126 sheets of tin-foil, sparks twenty-eight inches long were produced when the current for the primary coil was supplied from only four quart cells of Grove's form of voltaic battery. With ten voltaic cells sparks thirty-five inches long were produced, and with thirty cells sparks forty-two inches and a half long. These were by far the longest electrical sparks that have ever been artificially produced, and were quite deserving of the epithet of mimic lightning which has been conferred upon them. It is quite worth while to contrast these sparks, more than forty-two inches long, and produced from thirty voltaic cells, with the spark but a trifle more than half an inch long, which is the ultimate effort of the 14,400 cells of the chloride-of-silver battery without the help of its condensers, as a practical illustration of the difference of high and low tension currents of electricity. With the twenty-eight-inch spark a block of flint glass three inches thick was pierced by the discharge. These induction coils are instruments by means of which the current of the voltaic battery, which has large heating, chemical, and magnetic power, is converted into an intermitting or spark discharge, of which the heating, chemical, and magnetic effects are less, but in which the difference of the potential, or resistance-overcoming force at the opposite terminals of a broken circuit, is of enormous strength. By means of the magnetic and coil induction, the current of low tension is converted into an intermitting discharge of high tension.

But the voltaic current itself is, in reality, a series of very rapid discharges. The proof of this was one of the objects which Dr. De la Rue had in view in the construction of this large voltaic battery, and he effected this portion of his purpose in a very ingenious and skilful way. He availed himself of the circumstance which has been already alluded to, that there is no secondary current induced in a secondary coil, unless the current which flows through the contiguous inducing coil is either an intermitting, or, at any rate, a pulsating, one, with waves of varying intensity following each other. He placed a primary coil in the closed circuit of the voltaic battery, and ranged in close contiguity with it a secondary coil of wire, which was connected in one instance with a vacuum tube, and in another instance with the coil of a galvanometer. The secondary coil, it will be understood, had no communication of contact with the primary one. It was quite insulated from it, and merely arranged in near contiguity. Whenever a current was produced by inductive or sympathetic action in the secondary coil, it declared itself either by lighting up the vacuum tube, which formed part of its own circuit, or by causing oscillations in the needle of the galvanometer. But if the voltaic current in the primary coil was absolutely continuous, without either break or pulsation of intensity, no current whatever would be caused in the secondary coil. In Dr. De la Rue's experiments, however, luminosity was produced in the vacuum tube connected with the secondary coil, and oscillations of the needle of the galvanometer presented themselves, whenever a current was started in the primary coil. It was, therefore, manifest that the voltaic current itself is essentially of the same nature as the stream of electric sparks presented in the discharges of high tension. It is merely a stream of electrical pulsations of such rapid succession that they quite elude all ordinary means of observation, and of such low tension that they are incapable of making their way through the minutest gap of non-conducting material.

This conclusion as to the pulsating or vibratory character of the voltaic current was most emphatically confirmed by a very beautiful series of experiments upon the aspect of the luminous discharge through vacuum tubes, which were made under varying conditions of exhaustion and resistance. Dr. De la Rue found it to be necessary

to produce his own vacua for these investigations, and he employed tubes of glass thirty-two inches long, of the form which is shown in Fig. 3.

The vacua were produced by drawing upon a three-fold power. The rush of a stream of water from a column of 106 feet high was first made to suck the air, or some gas representing it, out

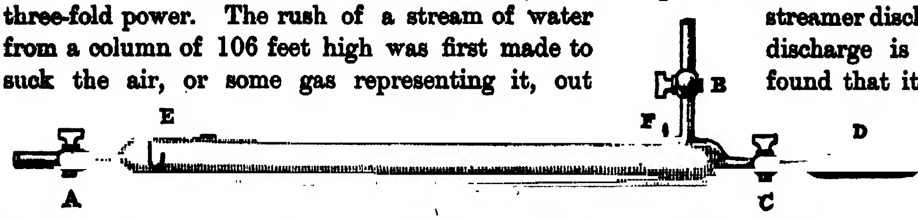

Fig. 3.—A Vacuum Tube of the Form employed by Dr. De la Rue in his Experiments with Cocks capable of being opened and closed at A, B, and C, with an Absorption Chamber at D, and with pieces of Platinum or Aluminium Wire inserted through the Glass, and hermetically cemented to it at E and F, so that their Points are 29 inches asunder.

through one of the opened cocks until the pressure within the tube was reduced to the sixtieth part of the ordinary pressure of the atmosphere. This cock was then closed, and two similar operations were performed in succession by the falling of streams of mercury past an orifice connected with a second cock,* until the pressure within the tube was reduced to between the two and three-millionth part of the pressure of the atmosphere. The perfection of even this vacuum was then further increased, in some special instances, where gases such as hydrogen or carbonic acid were used, by opening the connection with a chamber (Fig. 3, D) in which spongy palladium or charcoal had been previously placed, so that the chief part of the residual gas might be removed from the tube by the chemical attraction exerted upon it by either the palladium or the charcoal.

When the discharge of the large battery, with its full complement of cells, is passed through air, or through a gaseous medium at ordinary atmospheric pressure, between charcoal points held a short distance asunder, a glow, or stream of luminosity appears before any spark jumps from point to point, which is termed, by Dr. De la Rue, the streamer discharge. When this streamer discharge is closely scrutinised, it is found that it consists of two perfectly distinct parts. A series of twisted intermitting streamers issue from the positive terminal, extend beyond the opposite point, and then curl in towards it, whilst a continuous brush-like glow appears at the negative terminal, which is completely enveloped by the spiral streams without having its form in any way altered or interfered with by them. This appearance of the two opposite luminosities, the spiral streams, and the brush is represented in the accompanying wood-cut (Fig. 4).

When any increase of resistance is introduced into the conducting track which intervenes between the battery and the terminals, or if the condenser is attached to the terminals, the streamer discharge disappears, and a line of sparks issues in rapid succession between the points with tension enough to perforate strips of paper introduced into the line. The battery then gathers up at the terminals a charge which only escapes when the energy accumulated is enough to leap through the intervening gap of air. The sparks under ordinary circumstances follow each other in such rapid succession that they appear to form a continuous and unbroken line of light. When the condenser is used the interval between the successive sparks is lengthened out, because each one only occurs after the plates of the condenser have been charged

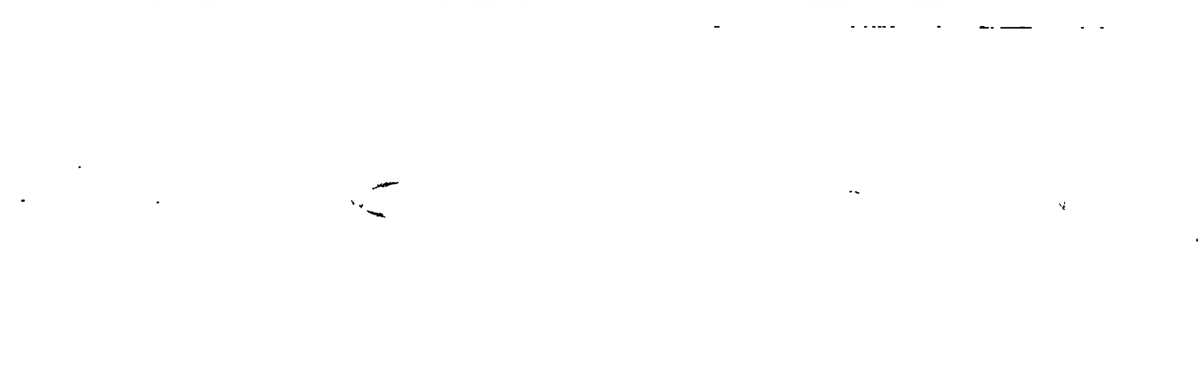

Fig. 4.—The appearance of the Streamer Discharge of a Voltaic Current between Charcoal Points at Ordinary Atmospheric Pressure, P being the Positive, and N the Negative, Terminal.

* This part of the process was carried out by the forms of mercurial air-pumps, technically known as the Alvergniat and Sprengel pumps: "Science for All," Vol. I., p. 109.

up to the point of their inductively retentive capacity.

When the carbon points are arranged in the interior of the vacuum tube, precisely the same series of effects take place so long as the air or gas within the tube remains under the ordinary pressure of the atmosphere; but when the air or gas within is subjected to progressive exhaustion during the discharge, the line of light that is formed by the discharge grows wider and fainter, until when about half the air or gas that was originally contained in the tube has been drawn out, the whole of the residual portion begins to glow, and the glow assumes a different tint with different gases that may be used in the operation. The entire tube is filled with light, the colour of which depends upon the nature of the gas that remains in the partially exhausted receptacle. This is the electrical discharge in the vacuum tube whose luminous appearance is now pretty well known to every one. As the rarefaction is increased, the discharge is more easily produced up to a certain point—that is, batteries of lower power are capable of producing the effect through tubes in which the terminals are some inches apart. But when this degree of exhaustion has been reached, the discharge becomes more and more difficult to sustain, until at last a vacuum is obtained that no discharge can pass through. Dr. De la Rue found that the discharge was most easily produced through hydrogen gas, when the exhaustion had reached the 845-millionth part of the ordinary pressure of the atmosphere: 430 cells were then capable of maintaining the discharge between terminals thirty inches apart. At a pressure of 8·6-millionths of an atmosphere, 8,937 cells were required; at 1·8-millionths, 11,000 cells failed to produce any discharge; at 0·07-millionth of an atmosphere, an exhaustion produced by the supplementary instrumentality of the spongy palladium absorption chamber (Fig. 3, D), and the nearest approach to an absolute vacuum that has yet been made, the 14,400 cells could produce no discharge. It may, therefore, be certainly looked upon as an established fact that absolute vacuous space does not favour the electrical discharge. The presence of material atoms in some form is essential to this result.

But when a vacuum tube is rendered narrow at one portion of its length, as in the form represented in Fig. 5, the luminous discharge shows a

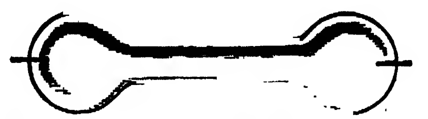

Fig. 5.—A Vacuum Tube constructed so that there is a Comparatively Narrow Central Part intervening between wide bulb-shaped ends.

tendency to break up into a succession of light and dark spaces, which are then technically spoken of as a stratification in the discharge. This peculiarity of the electrical discharge through rarefied media was first observed by M. Abria, in 1843, in connection with the effects of induction coils, but as long back as 1859, Mr. Gassiot was occupied with experiments contrived to show that the same characters in the discharge could be produced by the agency of voltaic batteries. He produced stratification in residual carbonic acid in a vacuum tube between terminals two inches apart with 3,250 voltaic cells, and he arrived at the conclusion that this seemed to indicate that the voltaic current is not a continuous, but an intermittent discharge, and that it consists of a series of pulsations produced in material molecules, of greater or less intensity according to the electro-motor strength of the battery, and to the resistance by which the transmission of the pulsations is opposed. He found that the number and position of the strata were materially affected by any alteration of the resistance of the electrical circuit. Fig. 6 reproduces the appearance which this stratification of the discharge assumed when the discharge of Dr. De la Rue's large battery was allowed to pass through a long vacuum tube which had been first charged with carbonic acid, and then exhausted until the pressure within the tube was reduced to something like the 800-millionth part of an atmosphere.

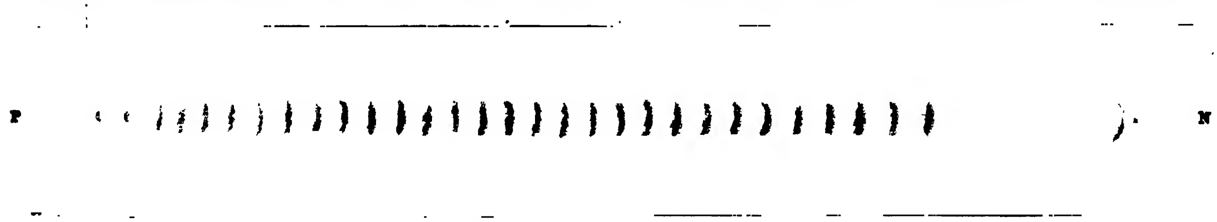

Fig. 6—Stratification of Discharge.

The explanation of this very beautiful characteristic of the discharge most probably is that the residual atoms contained within the tube are gathered up under the play of the electrical force into a series of isolated clusterings, and that each one of these becomes electrically charged on its own account like a miniature Leyden jar, with concentration of the negative disturbance on one side, and of positive disturbance on the other. The discharge then takes place by jumping progressively from cluster to cluster. The electrically-formed drop-like groups do not themselves move along the tube in the direction of the discharge. The discharge simply leaps from cluster to cluster, making stepping-stones of them, as it were, by the way. When the stratification begins to appear, a luminous spot first presents itself at the positive terminal within the tube. This, then, detaches itself, and moves towards the negative end of the tube, and is immediately followed by other similar luminosities, which increase in number up to a certain limit, and arrange themselves somewhat like beads upon a string, until they extend through the greater part of the tube. But a dark space is invariably left between the last bright spot and the negative terminal, and this dark space becomes of wider span as the exhaustion within the tube proceeds. Mr. Crookes considers this interval of darkness as coinciding with what he has termed the "free path" of the molecules, shot-off in the attenuated medium from the negative terminal—that is, the distance which these molecules have to move before they come into collision with other molecules to produce the shock of luminous vibration. The dark blank space immediately appertaining to the negative terminal is very clearly shown in connection with the stratification represented in Fig. 6.

Dr. De la Rue remarks that when the two and a half inches of gold wire were dissipated into metallic dust by the discharge from his battery, the stain upon the glass plate, under the examination of the microscope, gave clear indications of a stratified distribution, such as might be expected to be produced by the pulsating progress of a vibratory disruptive force. It is also observed that in the vacuum tube metallic particles are not unfrequently carried by the discharge from the wire terminals to the surface of the glass, and that in cases where stratified discharges have been maintained, these metallic deposits upon the glass to some extent assume the broken and interrupted character of the stratified light. Dr. De la Rue, in one of his papers on the stratified discharge, suggests that ball-lightning may possibly be of the nature of the single luminosity that first appears with diminishing pressure at the positive terminal of an exhausted tube, charged like a Leyden jar, and projected forwards by an electrical impulse from behind. The bending of the line of light in a partially-exhausted tube, which is observed to take place when a finger is presented from the outside towards it, is obviously an effect of induction. The finger sets up an inductively attractive spot by the deposit upon the outside of the tube of a charge of an opposite kind of electrical disturbance.

One of the most beautiful of Dr. De la Rue's experiments consisted in the formation of an artificial aurora, upon a miniature scale, in the interior of a large tube. The pressure of the contained air was first reduced by exhaustion to the one thousand three hundred and sixteen-millionths of an ordinary atmosphere, and the discharge of 14,400 cells was then passed through the interior space from a spherically-curved plate at the positive pole to a point constituting the negative terminal at a distance of seven and a half inches away. A glow of carmine coloured light with parallel streamers, arranged as represented in the accompanying diagram (Fig. 7), immediately appeared at the positive terminal (H), and extended half way down the tube towards the negative end (N). The resemblance of this luminous discharge to an ordinary auroral display was singularly suggestive and exact. It was found that the least resistance to a luminous discharge occurs with atmospheric air at a pressure of about four hundred and ninety-eight-millionths of an atmosphere. This, under the diminution of pressure that prevails with ascent into the higher regions of the atmosphere, would occur at a height of thirty-seven miles and a half above the level of the sea. Dr. De la Rue hence infers that this would be about the elevation in the air which is most favourable to an auroral display. At a height

N

Fig. 7.—Artificial Aurora produced in an Exhausted Vacuum Tube by the Discharge of 14,400 Cells of the large Battery.

of eighty-one miles and a half the natural rarefaction of the air corresponds with an exhaustion in the tube that would mark a pressure of only the 0·07-millionth of an atmosphere. But that is the pressure at which 11,000 cells failed to cause any discharge, even through a residual charge of hydrogen gas, which is more easily permeable by the discharge than air. At the height of 124 miles the pressure would amount to only the 0·0001-millionth of an atmosphere, a rarefaction so extreme that it would be impracticable for any kind of electrical discharge to take place through it. The height of 281 miles, which has been sometimes spoken of as being the probable seat of an auroral display, would present a tenuity of air forty thousand million times as great as that which would attain at 124 miles. From these considerations the conclusion has been drawn that thirty-eight miles is most probably the height at which the most brilliant auroras take place, that a pale and faint glow may possibly be produced as high even as eighty-two miles, but that at a height of 124 miles no auroral discharge is possible.

The character of the discharge does not appear to be appreciably affected by the nature of the metal through which it is made, excepting that a terminal of aluminium seems to give a somewhat lengthened spark. The intermissions in the discharge are more marked at the positive terminal than they are at a negative pole. Dr. De la Rue calculated that in some cases there may possibly be thousands of millions of discharges from the negative terminal in a second.* The form which the segments of the luminous stratification assume varies considerably with the nature of the residual gas. The segments are disc-like, with cyanogen and carbonic acid, and of an umbrella, saucer, or tongue-like shape, with hydrogen. The number of the strata in any given discharge is, within certain limits, increased as the pressure of the residual gas is reduced, and also as the strength of the electrical current is diminished. The condenser proved to be a very serviceable ally in prosecuting the experiments with alterations in the strength of the discharge, because it was found that it continued to discharge itself with a progressively diminishing intensity, after it had been quite disconnected from the battery, for something like ten minutes, so that the varying phases of the luminous stratification could be marked as the charge ran down.

One of the most notable of the results that Dr. De la Rue has secured by his skilful employment of this splendid piece of electrical apparatus, perhaps, is that he has made the luminous discharges within the vacuum tubes photograph themselves by their own light, so that very exact and durable records of their individual peculiarities have been in this way procured.

THE HEART AND THE BLOOD.

By Andrew Wilson, Ph.D., F.L.S., etc.,

Examiner in Natural History, University of Glasgow.

One of the first observations anyone makes regarding his own life-history, is that in every part of our frame there exists a red fluid —the blood—which flows from our bodies when these happen to be wounded, and which, moreover, is mysteriously connected in some fashion or other with the maintenance of life itself. When the child pricks its finger with a pin, it becomes aware of the existence of this fluid, and views the flow thereof from the miniature wound with feelings of alarm. And, by common consent, the loss of this fluid has come to be regarded as one of those exigencies of life which it is but right and proper we should do our very best to avoid. A kind of elementary physiology is thus acquired in early life through the media which the common accidents of daily existence present. Everyone, gentle or simple, tacitly repeats the Scriptural idea that "the blood is the life," and recognises that statement as a plain recital of a paramount fact of our existence. Unfortunately, however, the search after a knowledge of our bodily belongings is apt to end with the elementary facts just detailed. How blood flows, what is the use of its flowing, or why, indeed, it flows at all, are questions which are but too rarely asked in common life. And yet no more interesting field of inquiry exists than that which

* This estimate was made by watching the appearances of the discharge in a rapidly revolving mirror. Breaks could be distinctly seen in the image of the positive discharge when the negative discharge presented itself as a continuous sheet of light.

deals with the structure and mechanism of the heart, and with the manner in which the vital stream is distributed throughout the living frame. That the heart is concerned in this process of distributing blood through the body is a fact we learn more by intuition than by actual knowledge or experiment. Possibly, in the minds of many the exact functions of the heart still form a veritable mystery, and this for the plain reason that in ancient times the heart was regarded, and perhaps not unnaturally, as the seat of *mind*. The ancients, ignorant of the manner in which blood was distributed through the body, were yet aware that the beating of the heart responded to the emotions which coursed through the mind. They knew then, as we know now, that the heart increases its pulsations under joy, and slows them under sorrow; whilst its beat may well-nigh be stilled entirely under the dominance and sway of terror and fear. It was not wonderful, therefore, that the heart itself should come to symbolise the mind so completely, that even in these latter days we are accustomed to speak of "good-hearted" and "bad-hearted" persons —meaning all the while the "minds" of the subjects concerned, and not the central organ of the blood-system.

To the question, "What is a heart?" which may very properly preface all our inquiries into the history of the organ, we may at once reply—*a hollow muscle.* Any heart, no matter how complex, or how simple its structure may be, corresponds to this description. It is, firstly, "hollow," that it may allow blood to pass through it; and it is, in the second place, a "muscle," that it may contract, and so expel the blood from its hollows or cavities, or *chambers*, as they are also called.

When we say that the heart is a muscle, we make a statement of the utmost importance in respect of the essential nature of the organ. We thereby indicate that it is of essentially the same nature as the ordinary flesh of our bodies, which clothes our bones, and by means of which we perform all the ordinary movements of life. Thus to say that a heart is a muscle, means that its movements, however complex they may seem, are in reality of exactly the same nature as those by which we move our finger in writing a letter, or as those by which we wink an eyelid, or take a step in walking. Much of the mystery attaching itself to the idea of a heart is therefore dispelled by this first observation. Its motion, so far from being utterly unlike that of any other organ in the body, is found to belong to the category of the commonest movements which characterise the higher forms of animal life. Examining the substance of any heart, we find that substance to be "flesh," or "muscle," as the anatomist terms it. Whoever has seen the heart of a bullock, or other animal, hanging in a butcher's shop, knows that the substance of the organ is exactly similar to that of the meat or "muscle" we eat. If we place a few fibres (Fig. 1) of the heart's

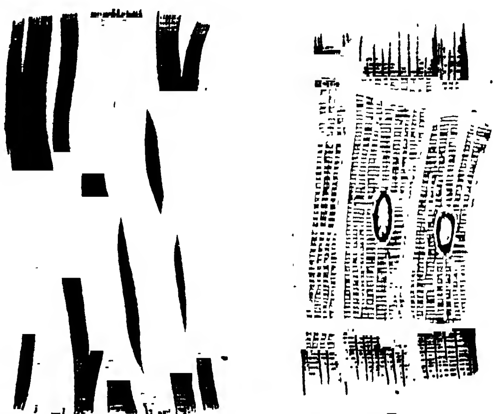

Fig. 1.—Muscular Fibres of Heart.
A, Fibres magnified, showing cross striæ junctions; B, further enlarged, showing divisions into separate nucleated portions.

substance under the microscope, we speedily discover that in all essential points its fibres resemble those of the flesh of the animal to which the heart belongs. The resemblance, indeed, is closer than at first sight we might expect. For, as the ordinary muscles of the animal are under the command of its will, and as the heart is entirely involuntary, and, as such, lies beyond the command of the will, we might expect its structure to resemble that of those muscles which are involuntary. In other words, instead of the fibres of the heart resembling those of such muscles as the leg or arm muscles, we might expect its fibres to agree with those of the involuntary muscles of the stomach or blood-vessels. But as we find the muscles of the legs and arms to possess *striped* fibres of this nature, so we discover that the heart's fibres are likewise striped in their structure.

We thus lay a plain foundation for a further study of the heart, when we remember that it is, from first to last, simply a muscle; and that, secondly, its structure corresponds essentially with that of every ordinary muscle of the body. The heart thus performs its work because, like every other muscle, it can contract—that is, it possesses the power of shortening its fibres. In so doing, it necessarily compresses the hollows or cavities it contains, and thus expels the blood which has entered them.

The heart, like every other organ of the animal

body, undergoes a progressive advance as we pass from lower to higher grades of life. In the Invertebrate animals, or those which do not possess a spine, the heart varies in complexity, as in the vertebrate series itself. In the worm group, the heart is a simple tube, from either extremity of which blood-vessels are continued. By its wave-like contractions, this simple heart propels fluid throughout the animal's frame. In the insect, the heart is a contractile tube lying along the animal's back—a situation it occupies in all *Arthropoda;* to which group the spiders, centipedes, and crustaceans belong. In the lobster, for example—the structure of which animal has already been investigated—the heart is found to be a simple sac or contractile bag, lying just beneath the shell of the back. In the mollusca, or shell-fish group (Fig. 4, *h*), the heart occupies a similar position; but it varies in complexity from the heart of the insect and its neighbours. In the mussels and their allies, the heart may be either two-chambered or three-chambered; whilst in the cuttle-fishes, the heart is more complex than in the snails, whelks, &c., as has already been detailed in the paper devoted to the description of the cuttle-fish class.

Beginning with the fishes, as the lowest members of the vertebrate series, we find them to possess a heart (Fig. 2, *h*) which consists, in all save a very few, of two chambers or compartments. These compartments are respectively named auricle and ventricle; the former receiving blood, whilst the latter cavity propels that fluid from the organ. A frog, as representing the second class (*Amphibia*) of the vertebrate group possesses, as we have seen in a previous paper, a heart consisting of three chambers, an additional auricle being added to the more primitive heart of the fish. In the reptile group (Fig. 3) we likewise find a heart consisting of three chambers—two auricles, right (*ra*) and left (*la*), and ventricle (*v*)—as in the frog; but in the crocodiles the common and single "ventricle" becomes divided to form two cavities, and thus places these reptiles in possession of a four-chambered heart. Lastly, in birds and in quadrupeds (including man), the heart is four-chambered. It consists in these latter groups of two sides, each divided into an "auricle" and "ventricle." This is the highest type of heart in the animal series; and as we shall observe, it performs more complex functions than the apparently similar heart found in the crocodiles and alligators. For, as one heart differs in the complexity of its structure from another heart, so hearts are likewise found to differ in the exact functions they perform. All "hearts" perform, of course, the same broad function—that is to say, they are organs devoted to the propulsion of blood. But whilst one heart is found to perform a comparatively simple function in this respect, a second may be seen to possess increased complexity of its duties. In illustration of this fact, let us select the heart of an insect or snail, and compare it with that of the fish and quadruped respectively. In the insect and snail (Fig. 4) the heart has but a single duty, so to speak, to perform. In either animal, the heart receives pure blood from the breathing-organs, and in its turn propels this purified (or arterial) blood through the body. The heart in insect and snail may, therefore, be appropriately called a *systemic* heart. It drives pure or arterial blood throughout the "system," or body; and this, moreover, is its only duty.

Fig. 3.—Heart of Reptile.

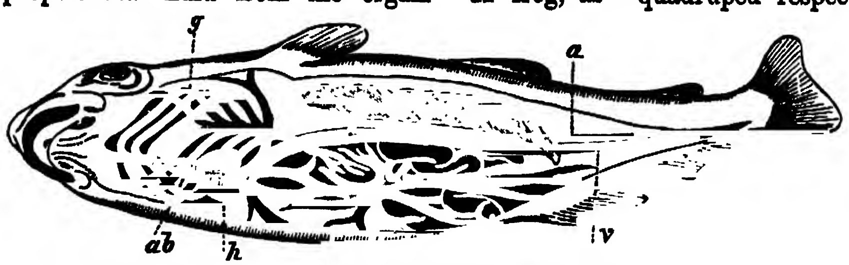

Fig. 2.—Heart and Circulation of a Fish.
h, heart; *ab*, bulbus arteriosus; *g*, gill-arches; *a*, dorsal artery; *v*, dorsal vein.

Turning now to the heart of the fish (Fig. 2), we shall find that organ to perform a function of equal simplicity, but of an exactly opposite kind. The fish-heart is two-chambered, and consists, as we have seen, of an auricle and ventricle. Impure or venous blood, which, having nourished the body, is destined to pass through the gills—there to be purified by receiving oxygen, and getting rid of waste matters—is received into the auricle

of the heart in the fish. From the auricle, the blood passes into the ventricle, and by the ventricle it is propelled into the blood-vessels, which by their branching and ramification, form the essential parts of the gills, being purified in the gills. The blood now leaves these organs, and passes into the main arteries, to be distributed thus-

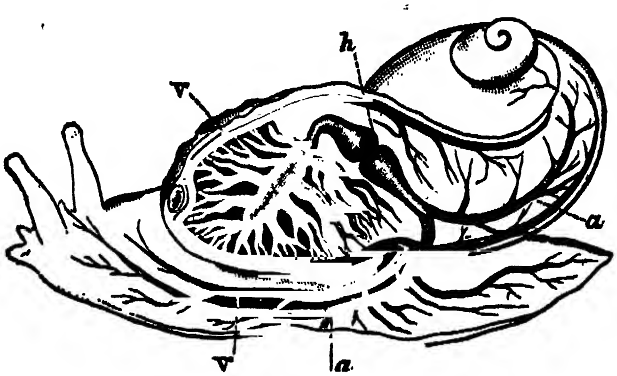

Fig. 4.—Heart and Circulation of Snail.
h, heart; *aa*, main arteries; *vv*, veins.

wise to the body for nutrient purposes. Thus the only blood which passes through the heart of the fish, is venous or impure blood. In this respect alone, it is opposed to that of the insect and snail. Then, secondly, as we named the heart of the latter *systemic*, because it sent blood to the system, we term the fish-heart a *branchial* or *venous heart*, because it is solely occupied in sending blood to the gills. It follows, therefore, that a heart in lower animals (*e.g.* snail) may either send pure blood, which it receives from the breathing-organs, through the body; or it may conversely (as in the fish) send impure blood, which it receives from the body, to the breathing-organs for purification.

Let us next inquire in what respects the heart of man, birds, and quadrupeds differs from these more elementary organs of the circulation. Firstly, it becomes evident from a very cursory examination of man's heart—taking the human heart (Fig. 5) as the type of the highest development of the organ—that it is in reality a double heart. It consists of two sides—a right and a left side—completely shut off from one another. In this respect it is like two semi-detached villas, which, though built together, are yet separated by a common or partition wall into two essentially distinct tenements. Blood cannot pass from the right to the left side directly, or *vice versâ*, any more than the resident in the one villa can visit his neighbour through the partition-wall. Each side of the human heart is divided into an auricle (and a ventricle), so that each side essentially corresponds in fundamental structure with the heart of the snail and with that of the fish. Blood can pass freely from the auricle of each side into the corresponding ventricle, just as the person in the front room of each villa can pass into a back room thereof. Bearing in mind these simple details, let us now trace the course of the circulation in quadrupeds and birds. What can be detailed in a few moments, it is profitable to remember took centuries to discover. It was only in 1619 that William Harvey placed the corner-stone upon this particular physiological edifice by teaching the true course of the blood through the body, after laborious experimental investigation upon both living and dead animals. It matters not, of course, at what special point of the circulation our researches begin, inasmuch as the essential idea of a "circulation" will naturally invest us with the belief that we shall arrive in due course, and after our physiological journey, at our starting-point again. For the flow of blood is not like the flow of water in a river. The constituent parts of the blood "go the round" of the body many times in succession; many particles being worn out and cast off in the course of even a single "round," whilst new parts are continually being added from the materials supplied by the food.

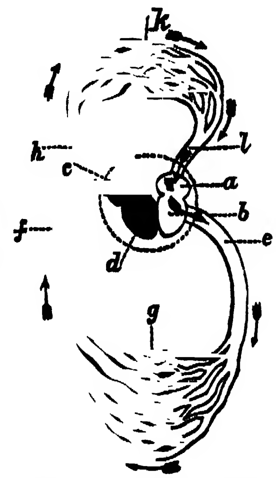

Fig. 5.—Diagram of the Circulation in Mammals and Birds.

The course of the circulation is depicted as observed from behind (the observer's right thus corresponding with the *left* side of the heart). The venous course of the circulation is indicated by the cross-shading, the arterial system being left white. *a*, Left auricle of heart; *b*, left ventricle; *c*, right auricle; *d*, right ventricle; *e*, aorta, or great artery, proceeding from left ventricle; *f*, *vena cava*, or great venous trunk, terminating in right auricle; *g*, systemic circulation; *h*, pulmonary artery, carrying venous blood to lungs; *k*, circulation in the lungs, or pulmonary circulation; *l*, pulmonary vein, returning purified or arterial blood to left auricle. The dotted circle represents the pericardium, or enveloping sac of the heart, and the arrows denote the course of the circulation.

Beginning, for convenience sake, at the lungs, we find pure or arterial blood passing from the lungs into (1) the *left auricle* (*a*) of the heart. From the left auricle the blood is sent into (2) the *left ventricle* (*b*). This latter cavity, in turn sends it out through (3) *the body* (*g*), to all parts of which it is conveyed by the *arteries*, and their minute branches, the *capillaries*. In due time, and having performed its nutrient mission, the blood becomes loaded with waste matters

derived from the tissues. No longer of a bright red hue, it has become of a dark purple colour. It now passes into the veins, to form which the capillaries gradually unite. By the *veins* (*f*), the blood is carried to the (4) *right auricle* (*c*) of the heart. From the *right auricle* it passes into the (5) *right ventricle* (*d*). This latter chamber then sends it to the (6) *lungs* (*k*); where, being purified it is returned to the (1) *left auricle* with which we began our recital of the blood's journeyings.

If the preceding account has been duly mastered, it follows that the main facts of the circulation may be briefly stated thus :—

Firstly, that the right side of the highest heart may be called the *venous side*, because only impure or venous blood passes through it; or it may be named the *pulmonary side*, because it is concerned solely with sending impure blood to the lungs for purification.

Secondly, the left side of the heart may, conversely, be named the *arterial side*, because pure or *arterial blood* alone passes through it; or it may be termed the *systemic side*, because it distributes blood throughout the "system" alone.

Thirdly, the right side of man's heart thus corresponds, in function, with the whole heart of the fish; and the left side of man's heart agrees, in function, with the whole heart of the snail. In a word, the higher heart unites in itself two distinct functions. It is anatomically, as well as physiologically, a duplex organ.

If we investigate how circulation is carried on in frogs and reptiles, we shall discover that the intermediate condition between a purely venous and purely arterial heart is therein illustrated. Both auricles (right and left) in frog and reptile (Fig. 3) open into the single ventricle. Whilst the right auricle receives impure blood from the body, the left receives pure blood from the lungs. Both pure and impure currents meet and mingle in the ventricle, which, in its turn, distributes this mixed fluid at once to lungs and body. Practically, there exist arrangements, in the frogs especially, whereby pure blood is sent to the head at least. But notwithstanding these special arrangements, such a circulation as that just noted, is decidedly inferior to the perfect double circulation of quadruped and bird.

When the structure of the higher heart is examined, that organ is found to present a disproportionate thickness of its left ventricle. In a sheep or bullock, and in bird as well as man, the muscular walls of the left ventricle are twice, or even three times, the thickness of those of the right; the right ventricle having to propel blood merely to the adjacent lungs; whilst the left ventricle has to propel blood through the system. On the plainest principles of natural utility, the latter maintains a precedence in strength over the former. It is extremely obvious, likewise, that the regulation and flow of blood through the various cavities of the heart must be subject to the control of structures adapted to guide the flow through the various apertures of exit and entrance which exist in the organ. Now, in this respect, the heart resembles any ordinary piece of mechanism through which fluids pass in a definite order—such as a pump, for instance. As means exist in a pump for preventing the reflux of water into the cistern or well, so means have been contrived by nature for the prevention of any backward flow of blood in the heart. Thus, when the left auricle of the heart (Fig. 6, LA) contracts, blood is

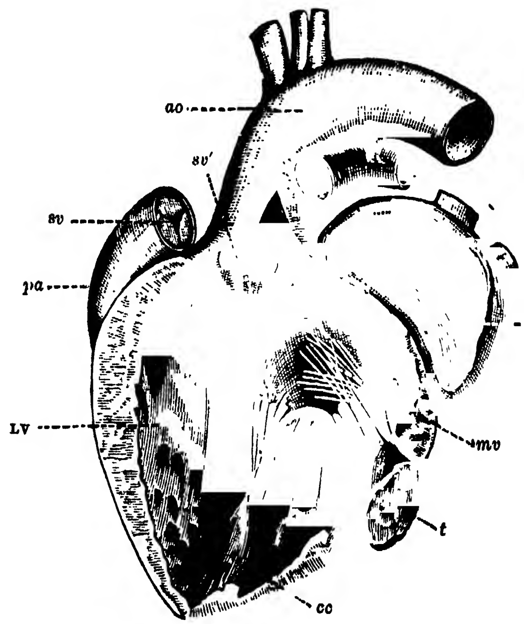

Fig. 6.—Dissection of Left Side of Heart of Man, showing Valves.
LV, Left Ventricle; LA, Left Auricle; *mv*, Mitral Valve; *pa*, Pulmonary Artery; *sv*, Semi-lunar Valves of do.; *ao*, Aorta; *sv'*, Semi-lunar Valves of do.

forced, as we have seen, into the left ventricle (LV). When the ventricle contracts blood is forced therefrom into the main artery (or aorta, *ao*), whose branches lead the blood everywhere through the body. What, it may be asked, prevents the blood from going back into the auricle when the ventricle contracts? And what prevents blood from returning into the ventricle when that chamber has just forced it outwards into the main artery? Exactly similar queries might be made with reference to the right side of the heart. In both cases the answer

would be similar to that which replied to the question how the flow of water through a pump is regulated. In a word, the flow of blood, like the flow of water, is regulated by means of *valves*.

Between the auricle and ventricle of each side are placed certain flaps or folds of the lining membrane of the heart. These flaps, existing to the number of two on the left side, form the bicuspid or mitral valve (*mv*). On the right side three flaps similarly form the tricuspid valve, which exists between the right auricle and right ventricle. These flaps fall back into the ventricle like so many swing-doors as blood pours into that cavity from the auricle. As the ventricle fills, the flaps are floated up on the blood, until their edges meet, when they form a cross partition, separating ventricle below from auricle above. A series of strong cords (Fig. 6, *t*), bind the flaps to projections of the wall of the ventricle below (*cc*), and allow the flaps to be floated up just sufficiently far, and so that their edges meet exactly to form a barrier to the blood. Thus when the ventricle contracts, the blood cannot pass back into the auricle, and its outward flow is thus duly provided for. Similarly, two sets of *semi-lunar valves* (*sv*, *sv'*) prevent the return of the blood into the right and left ventricle respectively. These latter valves consist each of three pockets, placed in a circle at the entrance to the great vessel which leads from each ventricle. The pockets open away from the ventricle, so that blood readily passes upwards, and past their mouths. If, however, any reflux of blood takes place the returning blood fills the pockets, so that by their distended edges meeting in the centre, they effectually block up the backward passage to the ventricle.

The discussion of the nervous regulation of the heart, along with other and equally interesting matters, lies outside the scope of the present paper. It may, however, be permissible to refer to two points of general interest in connection with the circulation at large. The first of these latter points refers to the fact that although the heart of an animal seems to work continuously, it nevertheless has its periods of rest. The lines which declare of the heart—

> "No rest that throbbing slave may ask,
> For ever quivering o'er his task,"

are decidedly erroneous, if their meaning be that the heart has no release from its task. That organ has a period of rest alternating with every stroke of work. Each stroke of a man's heart occupies about half a second of time, and the interval or rest is of the same duration. The heart, in fact, is in the position of a workman who takes his rest in short naps between his spells of work. Of the muscles of breathing the same remark holds good, with this difference, that the periods of rest and work in their case are five or six times as long as those of the heart. Measuring the heart's daily work, we arrive, by mathematical calculation, at the surprising result that if we could gather *into one stroke or lift* the entire force expended by a man's heart in twenty-four hours, we should be able to lift 124 tons one foot high (Haughton). That is what is meant by saying that the work of the heart in twenty-four hours, is 124 "foot tons."

The second and concluding point to be referred to concerns the uses of the circulation. The first use subserved by blood being everywhere sent through the body is that of *distributing nourishment* (in the shape of the elements derived from the food) to all parts of the body. A second use of the circulation is the *distribution of heat*. Thirdly, comes the *drainage aspect* of the circulation, in that the return flow through the veins carries to the *lungs*, *skin*, and *kidneys* waste matters, which are there got rid of. This constitutes the work of *excretion*. And fourthly, as the circulation carries blood to the various *glands*—such as the liver, salivary glands, gastric glands, &c., which respectively manufacture or *secrete* bile, saliva, and gastric juice—this latter use of the blood-currents is seen to be of high importance, inasmuch as, from the blood supplied to them, these glands manufacture fluids of use in digestion, and other bodily processes. This latter function of the circulation constitutes the work of *secretion*.

Last of all, a very important question may be asked in relation to the circulation, namely, what is the nature of the fluid which the heart propels along the vessels? This question may be answered in various ways. We may investigate the blood chemically, microscopically, or physically; that is, as to its material properties as a fluid. The microscopic examination of the blood reveals the astonishing fact that its red colour, so far from being a veritable reality, is due simply to an optical illusion, if we may so term it. When a thin film of blood is placed beneath the object-glass of a powerful microscope blood is seen to consist of a fluid as clear as water—the *serum* or *plasma*—and of an enormous number of bodies —the *corpuscles*—floating in this fluid. These corpuscles are of two kinds—*red* and *white*. The white are infinitely less numerous than the red,

and exist in the proportion of 1 to 400 or 500 of the latter. The red are so numerous that the unassisted sight, being unable to discern between them the clear *serum* in which they float, regards blood as a uniformly red fluid; whereas the truth is, blood is really colourless, and derives its red colour from the myriads of red corpuscles which float in it. In the blood of many animals—of which the lobster is a good example—there are no red corpuscles. The blood in such a case contains white corpuscles, which, in lobster as in man, exhibit those peculiar movements called *amœboid movements*, and which have already been described in a previous paper (Vol. IV., p. 108). In man the red corpuscles each average in diameter about the one-three-thousandth of an inch. The white corpuscles are slightly larger, and contain, besides, a central particle called the *nucleus*, which is wanting in the red globules. The blood-corpuscles of the frogs and their neighbours are amongst the largest that are known.

Chemically, blood may be said to present us with an epitome of the body's composition. Since its function is that of repairing and replacing the waste of the body, we should naturally expect to find in the blood the elements (derived from the food) of which the body is composed. Blood is thus found to be largely composed of water, albuminous matters, minerals, and other substances. Physically, blood clots or coagulates, as every one knows, when drawn from the living body. This result appears to be due to alterations which take place in the *fibrin* of the blood; this substance entangling the red corpuscles to form the "clot," which sinks to the bottom of the vessel, and leaving the serum or fluid portion to float above.

A BEE-HIVE.

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THE bee is one of the most fortunate of insects, for, unlike most of its class, having a practical "bearing," it has obtained more attention from naturalists than even its interesting economy would have attracted, and repays, in a tangible form, the care that man has bestowed upon it for his own profit and pleasure.

It is almost unnecessary to remark that the legitimate inhabitants of a bee-hive comprise four sets of individuals—namely, the queen bee, the workers, the drones, and the young in their various stages. Upon the workers all the labour, both inside and outside of the hive, devolves. The function of the queen is simply to lay eggs; while that of the drones is to fertilise the queen. Knowing this, we can begin our observations, and select for that purpose a hive in early spring, when the bees are commencing to resume their active work. The inhabitants of the hive in question are a queen bee, and a more or less numerous body of workers. The latter, warned by the increasing sunshine that the time of flowers has come, will probably soon begin to prepare the waxen cells known to every one as honey-comb. The way in which these cells are formed has not only been most carefully studied, but has given rise to numerous controversies, into which we need not enter, but content ourselves with briefly describing the chief points in the work of construction.

Amongst the worker bees are two sets of individuals, one of which is chiefly employed in elaborating the wax and in laying the foundations of the combs; while the other set, the individuals composing which are somewhat smaller than the wax-producers, complete the building of the cells, collect honey, and feed the young. For the production of wax, the wax-producing bees fill themselves with honey, and then rest without moving, but suspended to each other in a series of festoons (Fig. 1) for about twenty-four hours, during which the formation of wax is going on. The wax appears in the form of thin scales, which lie in the wax-pockets, as certain membranous bags situated between the rings of the under side of the abdomen are called (Fig. 2). Of these pockets there are eight, and the wax is formed by chemical changes in the honey that has been swallowed by the maker, and exudes through the thin membrane of the pocket. When the wax has been produced the worker goes to the place where the comb is being made, or is to be made, and clears a space to work in by turning itself round; it then seizes a scale of wax with one of its hind legs, passes it on to one of the front legs, which conveys it to the mouth, where it is

chewed, and mixed with a frothy exudation, till it has acquired the necessary pliability and tenacity. The bee then deposits the morsel of prepared wax against the place where it is to be fixed, and then proceeds to prepare the rest of the wax that she has secreted, till all is used up, when she retires, and her place is taken by another. In this manner the foundation of a new comb is laid, and is in effect a single line of wax, about a sixth of an inch high, a twenty-fourth thick, and about half-an-inch long, depending from the vault of the hive, for it must be remembered that the combs hang perpendicularly, with the mouths of the cells horizontal.

Fig. 1.—Wax-Producers during the time the Wax is being formed.

Fig. 2.—Bee, with the Plates of Wax appearing between the Segments of the Abdomen. *(Magnified.)*

The wax-producers having laid down the supply of wax, the other set of workers come and begin the moulding of the cells (Fig. 3). The comb, as already said, is to hang perpendicularly, and forms, as it were, a sheet of wax, the two faces of which are covered with cells, the bottoms of the cells of the one side being in close approximation to the bottoms of the cells of the other. The cells are fashioned by the builders in the following manner:—A bee takes up its position about the middle of the little wall of wax left by the wax-producers, and moulds with its mandibles a cavity to form the base of a cell. After working for a few minutes it is succeeded by another, who continues the work, deepening the hole and heightening the walls. After a time this bee gives place to another, and so on in succession, till perhaps more than twenty bees may have been engaged at this one cell. After this first cell has attained a certain size other bees commence, on the *opposite* side of the wall of wax, with the foundations of *two* cells, and continue working at them in succession till a certain height has been reached. The work is carried on till all the bases of the first row of cells have been accurately formed, after which they are polished, while other bees are commencing the second row. In the meantime the wax-producers have been busy laying down fresh wax for the builders to work with, and so the comb increases both in length and breadth, till it finally assumes the parallel-sided form that it possesses when finished. After the bases of some rows of cells have been made and polished, the next work is the construction of the walls of the cells, which is done by the builders in the same manner as they formed the bottoms of the cells. It is to be noted that the cells of the first row are five-sided, but that those of the other rows are six-sided. And now we must very briefly allude to a matter which has given rise to endless debate amongst students of bees. The questions in point are, are the cells mathematically exact? could one bee alone form such a cell? and are the bees guided by intelligence or by "instinct"? On all these matters very diverse opinions have been advanced; and it is only by comparing the work, and the manner in which it is done, of the honey-bee with that of other bees and wasps that any sound conclusion can be arrived at.

In the first place, as to the mathematical exactness of the hexagonal cells. It was for a long time considered that the cells were exact; but it has now been proved that such an exact cell exists only in theory, and that the cells are all more or less imperfect.* In the second place, could one bee alone form an hexagonal cell? This is a matter which is doubtful, but some authors think it probable that if a single bee constructed a cell it would be round, and not six-sided; while others, arguing from the cells constructed by certain wasps, think that a single bee

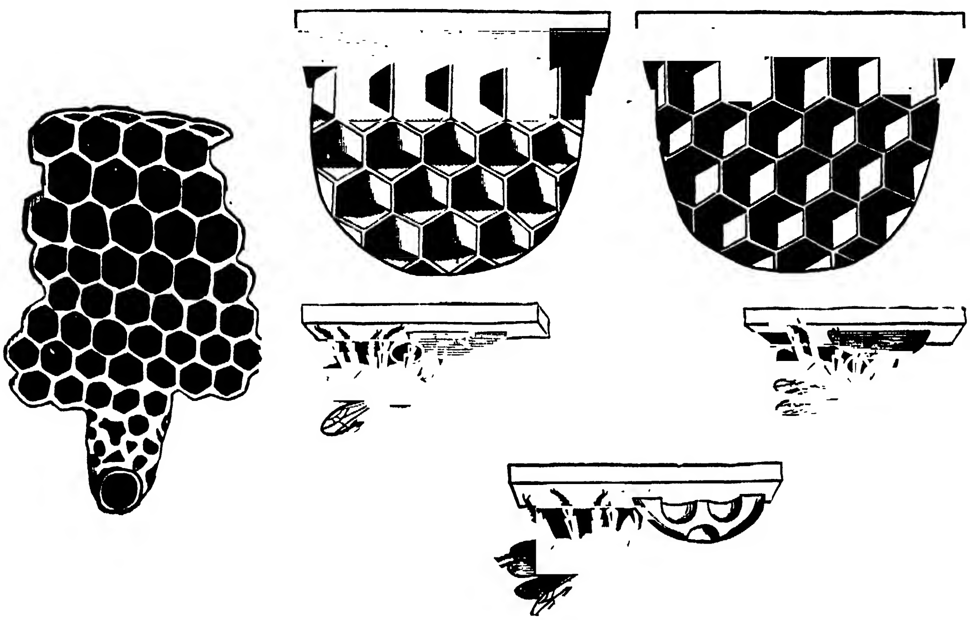


Fig. 3.—Cells in Process of Construction.

is quite capable of constructing hexagonal cells. To the third question we have asked, "Do the bees work intelligently, or are they guided by instinct?" the opinion of the late Mr. Frederick Smith was that they work intelligently, and one of his chief arguments in favour of the intelligence is that they readily make use of the artificial rudimentary comb that modern bee-masters are in the habit of supplying to their bees. This artificial comb consists of a sheet of wax, on each side of which is impressed a series of pyramidal hollows, representing the bottoms of the cells. On these the bees readily erect the cell walls, just as if they themselves had formed the bases of the cells. Mr. Smith was thereby led to form the opinion that we should cease to stigmatise the bee as a "mere machine."

The cells, which have given rise to so much discussion, though they may not be mathematically exact, are at least admirably calculated to economise both material and space. They are six-sided, with the base composed of three lozenge-shaped pieces, and so arranged that the base of a cell on one side is formed of portions of the bases of three cells on the other side of the comb.

The foundations of only one comb at a time are laid, but when the first comb has attained a certain length another comb is begun on each side of it, enough space (about half-an-inch) being left between each comb, to allow free passage, and room for working.

The ordinary six-sided cells vary somewhat in size, according to the use to which they are to be put. The purposes for which they are constructed are, first, as nurseries for the young; and second, as store-rooms for food. The cells in which the larvæ of the workers are to be reared are about $2\frac{2}{5}$ lines in diameter, while those for the larvæ of the drones or males are about $3\frac{1}{3}$. The latter kind of cells are usually, but not always, situated about the middle of the comb, and the bees in constructing them gradually increase the size of the worker-cells in the intermediate rows till the necessary size is reached—that is to say, there is no abrupt transition in size between the worker and the drone cells. The cells in which food is stored resemble other cells (which, in fact, are also used for this purpose), but are usually rather deeper. When the supply of honey is abundant the bees often increase the capacity of the honey-cells by adding a rim to them.

In addition to these hexagonal cells there is another kind of cell, in which the larvæ that are to produce queens are reared. These are quite different in form and size, being considerably larger, and pear-shaped (Figs. 4, 5). They are also not placed horizontally, like the other cells, but vertically, with the mouth downwards, and are generally

* Wyman: "Proceedings of American Academy of Arts and Sciences," 1866.

attached to the lower edge of the combs. In number, they vary from three or four up to thirty or more. These cells are not composed of such

Fig. 4.—Interior of Hive, showing Position of the Combs.

fine wax as the ordinary cells, but of much coarser stuff, and they require about one hundred times as much material.

Having now seen the nature of the habitation

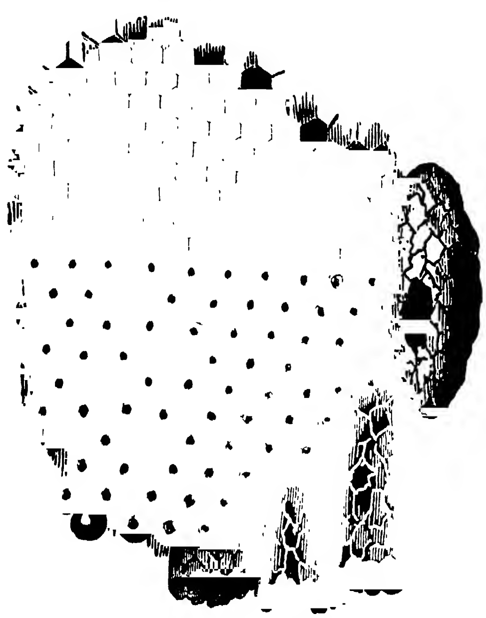


Fig. 5.—Royal Cells.

that the bees construct for themselves, we must take a glance at the manners and customs of the inhabitants of the hive, and, without any disrespect for her majesty the queen bee, will begin with the daily life of the workers, as it is by them that all the labours of the community are performed. Their work is to construct the interior of the hive (*i.e.*, the combs), and keep it in order, to collect food for the community, and to nurse the young.

The cells having been constructed in the way we have seen, the bees lose no time in making use of them. When the queen is moving about laying eggs—which are deposited one in each cell—she is attended by a small retinue (four to twelve) of workers. If from scarcity of cells, or some other cause, the queen, as sometimes happens, lays more than one egg in a cell, the workers in attendance are careful to remove all but one. When the eggs hatch the labours of the worker are increased, for they have to see that there is in each cell, along with the young grub, a sufficient supply of bee-bread. This bee-bread is composed of the pollen of flowers, which the workers are incessantly engaged in collecting, and storing up in cells in anticipation of the needs of the young brood. Before being given to the grubs, the bee takes the pollen into its stomach, where it is probably mixed with honey, and, in addition, undergoes some chemical change. It is then regurgitated in the form of a whitish jelly, and a sufficient quantity placed in the cell with the larva or grub. If we watch a piece of comb in which there is a young brood we may see bee after bee examining the cells to see if there is enough food in them, and where the food has been all consumed a fresh supply is deposited. When the grubs have attained their full size the workers seal the mouths of the cells with wax, the lids being nearly flat in the case of workers, and convex in that of drones. After that, the labours of-the workers cease as regards these; for the young bees, when arrived at the adult state, are able to extricate themselves from their cocoons and from their cells.

In addition to their nursing duties, the workers are the purveyors of food for the community. The materials used for food are the nectar and the pollen, or dust of the anthers, of flowers; but in addition to these they collect a substance called propolis, a kind of resinous matter not unfrequent on the buds of such trees as the poplar and birch, and which is used for giving a finish to the combs, and for stopping up crevices. Like the pollen, it is carried on the broadened tibia (pollen basket) of the hind leg of the bee (Fig. 6). When a bee returns

from an excursion she hastens to deposit her load. The honey that she has swallowed she disgorges into the cells prepared to receive it, first breaking with her front legs the thick skin that has formed on the honey already in the cell. It requires the contents of the honey-bags of a good many bees to fill a cell. Some of the cells containing honey are left open for daily use, but others are sealed with wax, and reserved as a store for the season when no honey can be collected. But a worker on returning from an excursion, does not invariably disgorge her load of honey into the honey-cells. Some of those who have been working at home are probably in need of food, and she employs part, or the whole, of the honey she has collected in feeding them.

As for the pollen brought back, it is disposed of variously, as circumstances may direct. The bee frequently summons others to her assistance by flapping her wings, and she and they then proceed to empty the pollen-baskets on her hind legs, and prepare the jelly, mentioned above, which is then used as food both for feeding the young brood and the adult bees. If, however, no bee-bread is required at the moment, the pollen is stored up in an empty cell; the laden bee puts her two hind legs into the cell, and pushes off the pollen with the intermediate pair of legs. She (or, if too fatigued by her labours, another bee) then enters the cell, and packs the bee-bread into as small a space as possible.

In addition to these duties, the workers keep the hive clean, and also attend to the ventilation. The latter is a very important duty, when we think of the great number of individuals inhabiting a confined space, and is effected by the vibration of the wings. A certain number of bees stand outside the entrance to the hive, while a still larger number take up their position on the floor of the hive, and, all vibrating their wings together, set up very perceptible (as may be learnt from experiment) currents of air. When a bee is tired of this occupation its place is taken by another, and so a continual ventilation is kept up, though the amount varies at different times.

Fig. 6.—Hind Legs of Bee: A, of Queen; B, of Worker, seen from inside; C, of do., seen from outside; D, of Male.

In watching the proceedings in a hive, it will be seen that bees sometimes go to empty cells, and enter them head-first, leaving only the ends of their bodies protruding. In this position they stay for a considerable time, and there is good reason for supposing that this is their way of sleeping.

Nothing has been said as yet about the use that bees make of the formidable stings with which they are armed. These are primarily weapons of defence, for it sometimes happens that bees from one hive will attack and rob another hive, and fierce battles then ensue between the robbers and the robbed. Another use of the stings is to kill the male or drone bees when they have ceased to be of use to the community; and we will now proceed to a brief sketch of the life-history of the latter. As already said, the cells in which the drones (or, rather, the ordinary-sized drones, for, like the workers, there are large and small drones) are reared are rather larger than the worker-cells, but in other respects their early history is similar. When arrived at adult life. the drones do not take

any part in the work of the hive; and, in fact, their span of life is not very long. The pairing with the queen, or queens, takes place outside the hive, and after that has been accomplished the workers fall upon the drones, and put them to death by stinging them, after which their bodies are dragged out of the hive and flung away. After this massacre the workers search out any male pupæ that may be left in the drone cells, suck the juices out of their bodies, and drag them out of the hive.

The life-history of the queen bee has now to be considered. As mentioned above, the larvæ that are to result in queens are reared in larger and different-shaped cells from those in which the workers and drones are brought up. But, in addition to this, queen larvæ are fed upon a different and more nutritious food than the other individuals, and it seems to be entirely due to this food, as well as to the larger and differently-shaped cell, whether the larva will result in a queen or in an ordinary worker. When we consider how different, in many respects, the queens and the workers are, this seems very curious; but it must be remembered that the workers (like the workers amongst ants) are really females, only less developed, and that in some instances they are able to produce eggs, which result, however, only in male progeny. But that the same kind of larva can be brought up so as to result in a worker, or in a queen, is capable of direct proof, for in hives that have accidentally lost their queen, and where no queen larvæ are being reared, the workers select some of the ordinary worker larvæ (from one to three days old), and feed them with the special queen food, or royal jelly, and thus raise up a new monarch. In addition to this special food, the larger size and different form of the cell, as well as its supposed higher temperature, are said to be factors in changing the destination of the larva so treated. It is said, however, that queens so reared (that is to say, which have not been treated as queen larvæ from their earliest infancy) differ in a slight degree from those born as queens.

In the preparatory states (egg, larva, and pupa), the queen takes a shorter time than the workers and the drones; they requiring, respectively, twenty and twenty-four days, while she needs only sixteen. There is also a difference in the cocoon spun by the queen larva. The worker and drone larvæ make cocoons which completely envelop them; but the queen larva covers only the head, thorax, and first segment of the abdomen.

When the queen has nearly arrived at the adult state, and the pupa is approaching maturity, the workers, who have made the wax at part of the cell so thin that the state of matters within can be readily ascertained, are very careful to watch that she does not make her escape before it is desirable that she should do so. The reason why they do this may be one of several; but before mentioning these we must notice the phenomenon called "swarming." When the population of the hive has increased beyond the capacity of the structure to hold it, a certain portion migrates to new quarters, and the colonists are led by the reigning queen. Before, however, she departs to found the new colony she lays eggs in the royal cells at intervals of some days (so that the coming queens may not all arrive at maturity at the same time). If, however, the swarming has been delayed for some reason, as through inclement weather, it may happen that the old queen is still in the hive when the first of the young queens becomes adult, and if the two were to meet, a battle, resulting in the death of one, or both of them, would be sure to take place. The workers, therefore, keep the young queen in her cell till the old one has departed. But a more frequent reason for her confinement is that the swarm that the young queen is to lead off may not be ready for her, and as, if she was allowed her freedom, she would probably proceed to the other royal cells, and put to death her younger sisters, she has to be kept a prisoner. When, at length, she is allowed to get out, the guard of workers still attend her, and prevent her, if necessary, from approaching the other royal cells. If, however, more queens are not required, she is permitted to search them out and kill them. It sometimes happens that two or more young queens are at liberty in the hive at the same time. When they meet they invariably fight, and the survivor reigns in peace. The queen bee has the power of uttering a peculiar sound, which has a remarkable effect upon the workers, commanding their immediate attention, and usually their obedience. It is said that queens which have been developed from larvæ originally intended to be workers, but which, in the manner mentioned above, have been subsequently brought up as queens, have not the power of emitting this sound, nor are they guarded so carefully as the ordinary queens.

The reigning queen is treated by her subjects with the utmost care and attention. She has always a retinue of workers in attendance upon her, and if by any means the hive is deprived of its

queen, and of the means of replacing her, the bees cease to work, and soon all perish. As we have seen, however, they have generally the means of raising up a monarch if required.

This, then, is a brief sketch of the habits within the hive of its legitimate inhabitants. It does not come within the scope of this paper to describe the proceedings of the bees when on their excursions; but before quitting the subject we must notice some of the illegitimate inhabitants of the hive, which are either parasites on the bees or live at their expense.

Amongst the parasites is the so-called bee-louse (*Braula cæca*), a minute flattish insect, which, though wingless, belongs to the order of the two-winged flies, or Diptera, and is allied to the sheep-tick, and some other animal parasites. It is blind, and clings to the hairs of the bee, and sucks the juices of its body. It is sometimes said that *Braula* is a parasite of the queen bee only; but this is quite erroneous. It attacks the workers as well, and though often there is not more than one or two (if any at all) upon a single bee, it occasionally happens that the parasites occur in great numbers, and cause much annoyance to their victims.

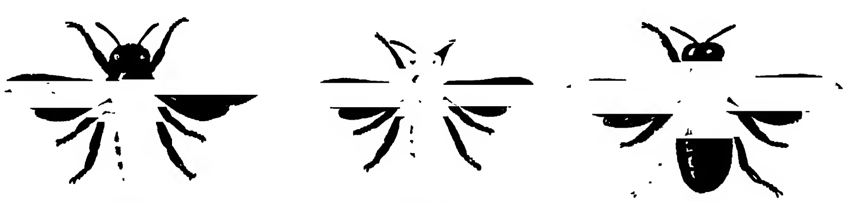
Belonging to the same order of insects (the Diptera) is another bee parasite—*Phora incrassata*—which, or rather its larva, is supposed to be one of the causes of the terrible disease known as "foul-brood." In some, if not in all, cases, the cause of this disease is, however, a vegetable parasite—a kind of mould, which, when once established in a hive, plays dire havoc with the brood, and is, moreover, very infectious.

The order of the beetles (Coleoptera) is said to furnish some other bee-parasites. Amongst these are species of oil beetles (*Meloë*), allied to the blister beetles or "Spanish fly" (also a parasite in its younger stages on wild bees), whose larvæ or grubs have a very curious life-history. The eggs are laid in the ground, and the young larvæ, when they emerge, find their way to flowers frequented by bees. At this stage the larvæ are minute, very active, louse-like creatures. When a bee visits the flower they spring on to it, and feed on its juices, and may be carried into the hive. Having arrived there they desert the bee, and eat the honey instead, and so far as the hive-bee is concerned their connection with it probably then ceases, as they seem to be unable to live to continue their metamorphoses. Should, however, the bee that they have attacked be one of the wild bees whose larvæ undergo their metamorphoses in closed cells, in which a supply of food has been stored up, the beetle grub lives at the expense of the bee grub and its store of food, and finally, after some very curious changes of form, arrives at the perfect or beetle condition. When a hive bee has been attacked by a number of the beetle larvæ it may suffer considerably.

Some other beetles are reported to be parasites of the bee, but space will not permit of these being further alluded to.

Other bee parasites include a kind of mite, which is common upon many insects, and also several intestinal worms of a low type. Amongst the latter are two hair-worms (*Gordius subbifurcus* and *Mermis albicans*), which are occasionally found inside the bodies of the drones, though how they come there has not yet been explained. In some of their stages these worms frequent water or damp places, and there the eggs are laid. It may be mentioned that it is through a species of *Gordius*, or hair-worm, being frequently seen in water that the curious belief (not yet even altogether exploded) arose that horse-hairs placed in water will turn to eels! These hair-worms, which are not unfrequent in various kinds of insects, are often several inches in length, and it is remarkable how they find room to stow themselves away within the bodies of their hosts.

Among the animals which, as they do not feed on the bees themselves, cannot be strictly called parasites, are some moths which are occasionally inhabitants of the hive. Of these, the caterpillars of two—*Achroia alvearia* and *Galleria cereana*—feed upon the wax, and in places where they have established themselves do much injury. They protect themselves from the bees by spinning silken galleries. Another moth, and one of very large size—the Death's Head (*Acherontia atropos*), so called from certain markings on the back of its thorax having a kind of resemblance to a skull,—



Queen. Worker. Male.

Fig. 7.—Domestic Bees (*Apis mellifica*).

occasionally visits the hives, and feeds on the honey, which it sucks up by means of its proboscis. The squeaking sound which this moth has the power of emitting has been supposed to have a similar effect upon the bees as the cry of the queen bee, and to prevent attack. In the south of Europe this moth is said to visit the hives not unfrequently.

In addition to these, bees have other enemies—such as mice, toads, birds, &c.—but as their assaults are usually made outside the hive, a consideration of them does not come within the scope of this paper.

In conclusion, it may be mentioned, that while in this paper the habits inside the hive of the common honey-bee of this country have been very briefly described, there are several other kinds of honey-bee which have been domesticated.

Our bee is the *Apis mellifica* of Linnæus (Fig. 6), and is the common hive-bee of Northern Europe and of North America. In South Europe another kind—the Ligurian bee, *Apis ligustica*—is frequently kept, and has been introduced into this country, and crossed with the common honey-bee. In Egypt and Asia Minor another bee—*Apis fasciata*—has been domesticated; while in other countries yet other species are kept, and there are other wild bees which might be profitably treated in the same manner.

SEEING BY TELEGRAPH.

By H. Trueman Wood, M.A.
Secretary of the Society of Arts, London.

SINCE the telephone has descended from the rank of a scientific marvel to that of a commonplace and useful piece of apparatus, there has been a demand on the part of the insatiable public for some device which will enable it to see what its friends are doing, as well as to hear what they are saying, at a distance beyond the range of the unaided eye or ear. Is there any chance of this being effected? and if so, what chance? We can only answer, there is a possibility, but, as yet, no great probability of it. Any day some one of our many searchers into nature's secrets may announce that he has found the key to the problem; but in all likelihood it will be by the use of some means not yet imagined or discovered, rather than by the development of any system now in use. Bell found that a plate of iron could reproduce every vibration of the human voice, and the transmission of speech was effected. If anybody will discover a means of reproducing at a distant station the variations in the light vibrations by which we are enabled to see, the transmission of pictures, or rather *reflections*, by telegraph will become possible.

Failing, however, such definite successes to record, it may be interesting to consider what is being done in this direction by several energetic workers who are striving in various ways thus to extend the limits of human vision.

The devices which have been employed are two. One of them is the invention of Mr. Shelford Bidwell, the other of Messrs. Ayrton and Perry Before, however, saying anything about the apparatus, let us consider the problem to be dealt with. In the telephone we have a transmitter, into which the sender of the message speaks. This transmitter is connected by wires with a receiving instrument, by which the sounds spoken into the transmitter are reproduced. Various devices are now used in the transmitter, but in all, the vibrations of the air caused by speaking are made to vary the electrical condition of the line wire. These alterations in the condition of the line affect the receiver in such fashion as to produce vibrations therein, which, by throwing the air into motion, cause sounds corresponding to those which first set the whole system at work.* Now, it is not difficult to imagine a similar apparatus applied to sight instead of sound: a sensitive plate or mirror at one end, a connecting wire, a second mirror at the other end, capable of being so affected as to absorb and reflect light precisely as the light is absorbed or reflected from the surface of the first mirror. The result would be that the image of an object thrown on the first mirror would be seen in the second, it might be in black and white, as in a photograph, or in all its proper

* For our present purpose it is not necessary to refer to the means by which the result above stated is effected, but the reader may be referred to previous papers on the Telephone and its allies (Vol. I., pp. 124, 180; Vol. IV., p. 307; and Vol. V., p. 147) for a full explanation of them.

colours. Unfortunately, this is as yet only a philosopher's dream. Nothing approaching it has yet been done, or is likely to be done. Perhaps it would not be far from the truth if it were said that the great difficulty lies in the fact that the impression of sound results from a series of successive impulses, whereas the eye, in seeing any object, receives a vast number of undulations impinging simultaneously upon it. In the telephone the whole plate receives and transmits one vibration after another, however rapidly they may succeed. In our imaginary "Teleoptical" apparatus, the plate would receive a great number at once, and each on a different part of its surface. We cannot well conceive a single wire transmitting all these different impulses simultaneously, and we must therefore suppose our imaginary plates to be made up of a great number of small pieces, each piece of one plate in correspondence with the corresponding portion of the other plate. We should then get a sort of mosaic which would represent, with greater or less accuracy, the original image, according to the minuteness of the pieces composing it. An illustration may make this clearer. Suppose Fig. 1 to be a plate made up of a number of cells, sensitive to light, and capable of affecting a current of electricity passing through them. Suppose Fig. 2 to be a plate made up of cells—shall we say—capable of emitting more or less light, according to the strength of a current passing through them. Each cell of Fig. 1 is joined up electrically with the corresponding cell of Fig. 2—1 with 1, 2 with 2, 3 with 3, and so on. We will now throw a dense shadow of a capital letter E on the first plate, the part of the plate not shadowed being brilliantly illuminated. The cells which are lighted will cause the corresponding cells of Fig. 2 to emit light, while the cells of Fig. 2 corresponding to the shadowed cells of Fig. 1 will remain dark. Thus we shall get our E in mosaic. Now, one-half of our supposition is possible,* the other is not. The reader will remember that in a selenium cell we have precisely what is wanted for the transmitter, a device which is affected by light in such a way as to offer more or less resistance to an electrical current. Unfortunately we have not as yet any material which will act conversely, will emit, or reflect, light, when more or less excited by electricity; and our plan, as above suggested, must await realisation until some such material is discovered.

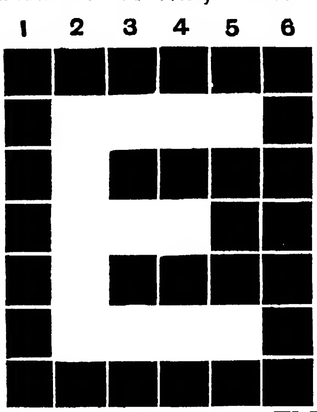


Fig. 1.—Diagram showing Mosaic of Sensitive Cells for Transmitting a Picture.

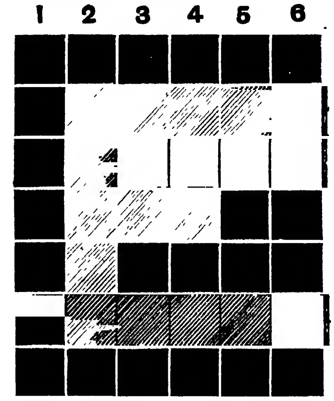


Fig. 2.—Diagram showing how a Mosaic of Sensitive Cells might reproduce a Picture.

Pending, however, this discovery, Messrs. Ayrton and Perry have devised a very ingenious method of exhibiting at one station the effect of light falling on a system of selenium cells at another—possibly a distant—station. As yet their work has not passed beyond the experimental stage, and the distance over which they have telegraphed has not exceeded the length of a lecture-room table. They have, however, demonstrated the possibility of sending—shall we say shadow pictures?—by telegraph; and this is alone a remarkable feat. It ought also to be stated that the notion of thus reproducing in mosaic the image of a distant object, seems to have been quite original with them.

The simplest way, perhaps, of getting a correct notion of the somewhat complicated apparatus which these inventors suggest should be employed, will be to consider the action of one unit of it, to see how the amount of light falling on a small square surface at Brighton can cause a similar surface at London to be illuminated with a corresponding amount of light. At Brighton we have a selenium cell—an arrangement of two wires laid as close as possible without touching, and the intervening space filled with selenium. An electrical current flowing through the system traverses the selenium more easily when a light is shining upon it than when it is in the dark.

Hence we get variations in the current corresponding with the amount of light falling on the selenium. Such variations can, of course, be detected by various means. Mr. Bell used a telephone, and hence his photophone. In previous experiments a galvanometer had been employed. Messrs. Ayrton and Perry cause the current to open and close a little shutter in a tube through

* "The Photophone:" "Science for All," Vol. IV., p. 307.

which light is admitted. In the end of the tube is a lens, arranged to throw an image of a square hole on a screen. When the shutter is open all the light passes through; when it is closed no light passes; in the intermediate positions more or less light passes. For our present purpose it is not necessary to describe precisely the arrangement employed. It may be sufficient to say that the shutter is attached to a small magnet, arranged like the magnet of a galvanometer, so that it is moved by the action of the electric current which passes through a coil of wire surrounding the tube in which the shutter and magnet are mounted. Fig. 3 shows the arrangement. With a mosaic of selenium cells at one station, and a mosaic of receivers such as Fig. 3 at the other, there seems no reason to doubt that we might get a reproduction, at all events, of the shadow of an object thrown upon the receiving screen.

Fig. 3.—Single Cell of Ayrton and Perry's Receiving Apparatus.

The next step would be to reproduce a picture such as could be thrown on the screen by a magic lantern, and the ideal would be to reproduce an image such as is formed on the table of a camera obscura, or on the ground glass of the photographic camera. But when an attempt is made to convert theory into practice, difficulties multiply. It is evident that even for experimental purposes a mosaic with ten cells in a row would offer but a limited field. Only very simple images could be thus transmitted. Such a square screen would require a hundred cells and a hundred wires. Now, the manufacture of selenium cells has not yet arrived at such a pitch of perfection that a dozen, let alone a hundred, similar cells could be readily turned out, while the notion of a telegraph line containing a hundred wires is quite out of the question. Messrs. Ayrton and Perry therefore propose to make a few rapidly moving cells do the work of a number of stationary cells, and they rely on the permanence of the impression on the retina of the human eye for the production of a picture. To do this the sending and receiving apparatus would have to move in precise unison, but it is believed this might be effected. The main idea of the proposal may be drawn from the following diagram (Fig. 4) of a piece of apparatus used by Mr. Perry to illustrate a lecture at the Society of Arts. D is a selenium cell, which is drawn across the dark and illuminated spaces shown upon the screen. E is a receiver, similar to Fig. 3. The light from E falls on a mirror, F, and is by it reflected on a curved screen, G. D and E are connected in an electric circuit with a battery. The string which moves D also gives motion to the arc H, at the centre of which F is fixed. If the light from E be uniform, motion of F on its axis will obviously cause the spot of light on G to move to the right or left. If the motion be rapid, a line of light will be seen. If the light from E be interrupted, a broken line of light will be seen on the screen when F is rotated. Now, as D passes through light or dark spaces its resistance varies; the result of this is the opening or closing of the shutter in E, and the consequent appearance on G of a broken line, corresponding with the spaces of light and dark in B. As constructed, the apparatus marked the passage of the selenium cell through the light and dark spaces, but it could not be worked at sufficient speed to give a continuous visual impression.

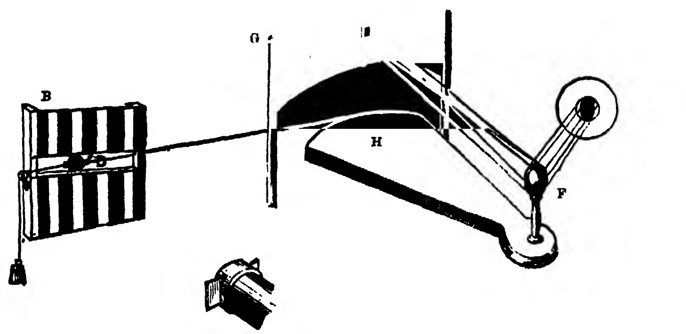


Fig. 4.—Model of Ayrton and Perry's Apparatus.

Mr. Shelford Bidwell's "Telephotograph" works in a totally different, but no less interesting fashion. The object of this ingenious apparatus is not to show you, as in a mirror, a representation of an object at any distance, but to produce, at a distance, a drawing of any object presented in front of the receiver, and held stationary there.

Fig. 5 is a diagram showing the principle on which Mr. Bidwell works. M is a metal plate on which is laid a piece of paper soaked in iodide of potassium—a salt which is easily decomposed by electricity. If a current be passed from a platinum style, P, through the moist paper, to the plate M, the paper is marked with a brown stain resulting from this decomposition. By drawing the style along while the current is flowing steadily, a line is marked on the paper. If the current be interrupted the line is broken, and thus a row of dots or dashes of any required length

may be produced. The effect is the same if the paper be drawn along under the style. In the diagram, B represents a battery in circuit through a galvanometer, G, with P and M. B′ is another similar battery, arranged in the same manner, but including also in its circuit a selenium cell, S. The current in this circuit flows in the contrary direction to that in the first circuit. The effect of this is that if the currents in the two circuits are previously equal, they will counterbalance each other, and no effect will be produced at M; but if the current in either circuit is stronger than that in the other, then a current equal to the difference

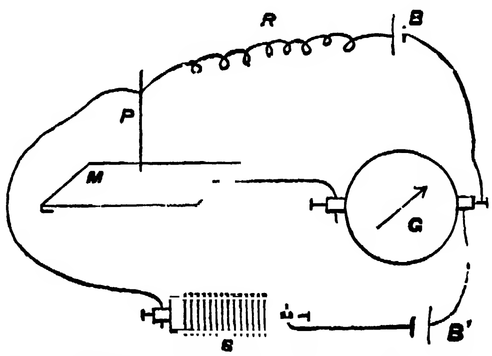


Fig. 5.—Diagram showing Action of the Telephotograph.

between the two will flow between P and M. We can make the two currents equal by inserting in the first circuit a "resistance," R, equal to the resistance of S, the selenium cell, in the dark. Then, if a light be thrown on S, the resistance in that circuit is caused to be less than the resistance of the other circuit, a current flows across the paper, and a mark is produced. If, then, the selenium is lighted and shaded at intervals, while the style is drawn steadily over the paper, we shall get a series of short lines, each line representing an illuminated interval, and the break between every two lines representing a shaded interval. It is not difficult to perceive that by a suitable arrangement of broken lines any figure can be drawn.

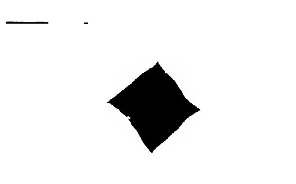


Fig. 6.—Form to be Reproduced by Telephotograph.

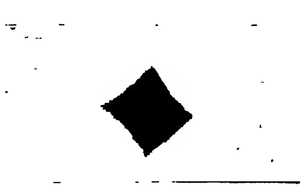


Fig. 7.—Reproduction by Telephotograph of form shown in Fig. 6.

Such a simple form as Fig. 6, for instance, would be represented by Fig. 7. which is indeed a reproduction of a bit of work actually done by the instrument. Instead of adopting any complicated mechanism to draw the marking style across the

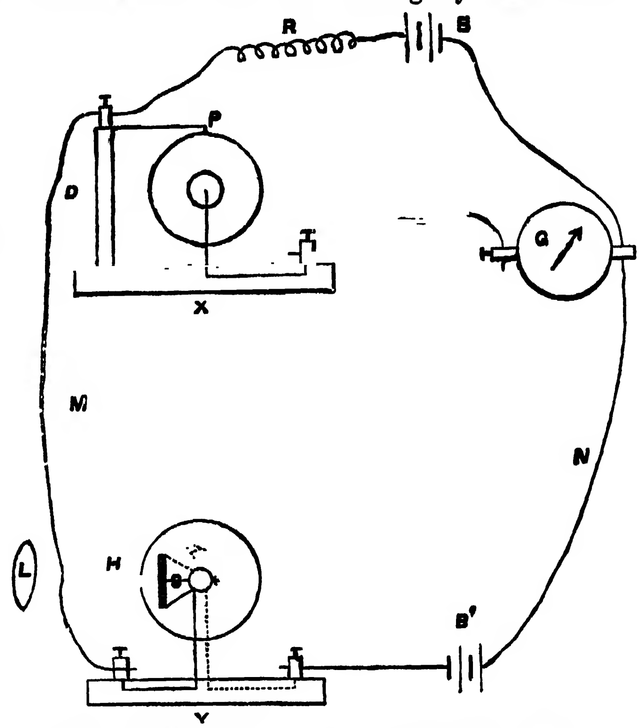


Fig. 8.—Diagram showing action of Telephotograph (Modification of Fig. 5).

paper in parallel lines, it is obviously simpler to put the paper on a cylinder the axis of which is cut with a fine screw, so that as it is turned it also travels along, and causes a point held steadily against it to describe a spiral line on the paper. When the paper is taken off the cylinder, the lines drawn spirally upon it appear practically straight and parallel, like the lines on the phonographic tinfoil, figured on p. 151. Such an arrangement is shown at X, in the upper part of Fig. 8. The arrangements here precisely correspond with those of Fig. 5, except that, instead of a simple selenium cell, we have the transmitter, Y. A platinum point, P, presses gently on the cylinder on which the prepared paper is placed. M and N in this figure represent the wires connecting the transmitting and receiving instruments; and the other letters (except H and L) represent corresponding parts with those of Fig. 5.

And now for the transmitter. It is evident that to produce the lines of Fig. 7 the selenium has to be lighted and shaded at intervals represented by the breaks in each line. No mere throwing of the shadow on the selenium will effect this. Let us see how Mr. Bidwell solves the problem. The selenium cell, S, is placed on

a stand within a cylinder capable of revolving, and having on its axis a screw precisely like that of the receiver. In the cylinder is a pin-hole, H. Now, while this pin-hole is opposite the face of the selenium, light shines through it on the selenium; when the pin-hole is at the back of the cell, the light passing through it is non-effective. By means of the lens, L, an image of the figure to be reproduced is focussed on the surface of the cylinder. When the pin-hole is in the shaded part of the focussed picture, little or no light passes through it; when it is in the bright part a good deal passes. In its spiral path the pin-hole covers successively every part of the picture, and thus the selenium is lighted up and shaded at intervals, which, if the receiving cylinder be rotated in precise correspondence with that of the transmitter, will be represented by discontinuous lines drawn upon the moistened paper by the marking style.

In the experimental apparatus both the receiving and transmitting cylinders are mounted on one shaft, so as to secure absolute synchronism. This uniformity of motion would have to be obtained by special means, if the apparatus were really set to work over any appreciable distance. This is a difficulty, but it need not be regarded as an insuperable one.

A BAR OF SOAP.

By the late Professor F. S. Barff, M.A., F.C.S.

EVERY one is familiar with the word salt; it brings to the mind the dinner-table; but, beyond this, it conveys to most people no further idea. If one were told that soap was a salt, one would probably hesitate to believe it; but let us examine the matter, and I think we shall see that soap has as much right to the name as the substance generally called "salt." In the early days of chemical science a salt was said to be something that would dissolve in water, but as the science advanced the views as to the composition of a salt changed, and now we know that a salt is formed by the union of two bodies, having opposite properties, which are more or less neutralised by chemical union, and that the salt formed has not the properties of its constituents. For example, if we take some tartaric acid and taste it, we pronounce it to be sour; if we taste some caustic soda (not carbonate) in solution, we shall find that it has a soapy taste. Now, if we mix together a solution of tartaric acid with one of caustic soda gradually, we shall find that both substances lose their flavour, and at last the mixture has what is called a saline taste. If, while performing this experiment, we from time to time dip into the solution a piece of blue litmus paper, we shall find that while the acid is in excess it will be changed to a red colour, but as we add more and more of the caustic soda solution the red will become fainter and fainter, till at last the paper will, on immersion, remain blue. Now, if we dip in a piece of pink litmus paper it will also be unchanged in colour. At this point the saline taste may be distinguished, and the substance formed is called a *neutral* salt. Caustic potash, and bodies like it, are called alkalies. And those bodies which have the opposite properties are called acids: when they are soluble they usually have a sour taste, but there are acids which have no taste at all. One of these was fully treated of whilst discussing the nature of flint (Vol. IV., p. 348). Now, salts are formed by the direct union of an acid with an alkali or base, or by the double decomposition of other salts when they act upon one another chemically. For example, lime is a base; when it is exposed to the air which contains carbonic acid this gas unites with the lime, forming carbonate of lime, which is, chemically, the same as chalk.

Lime is composed of 40 parts, by weight, of a metal called calcium, and 16 parts, by weight, of oxygen. The chemical symbol, Ca, represents 40 parts of calcium, and, as in former papers it has been stated that O means 16 parts of oxygen, therefore CaO will represent 56 parts of lime, when CaO unites with CO_2 (the symbol for 44 parts of carbonic acid).

$$\underset{\text{Lime.}}{CaO} + \underset{\text{Carbonic Acid.}}{CO_2} = \underset{\text{Carbonate of Lime.}}{CaO_3}$$

If, now, we take in a test-tube some chloride of calcium in solution, and add to it some carbonate of soda, also in solution, we shall get a white precipitate—shown in the annexed "formula"—Cl meaning 35·5 parts of chlorine, Na 23 parts of sodium (a metal):—

Chloride of Calcium.	Carbonate of Soda.	Common Salt.	Carbonate of Lime.

$$CaCl_2 + Na_2CO_3 = 2\ NaCl + CaCO_3$$

Here it will be seen that in both cases carbonate of lime is formed, and they are instances of direct union, and of double decomposition.

It is necessary that what has been said should be clearly grasped, in order to understand what takes place in the formation of soap. There are several sorts of soap. People generally are acquainted with but one sort; that is washing, or soluble, soap. Of this sort we know that there are many varieties, but they are all soluble in water. There are other soaps which are not soluble in water, and are therefore useless for household purposes. There is, for instance, lime soap and magnesia soap, of which we shall have to speak presently; also lead soap, which is used by surgeons as a plaster. First let us consider common washing soap. Of what is it made? Tallow and soda (not carbonate). What is tallow? It is a fat—the fat of animals. Large quantities of it come from Russia, and other countries. You have doubtless remarked the different sorts of fat met with in the same animal; also in different animals. Take, for instance, a cold boiled loin of mutton; the fat underneath where the kidney was is very hard and dry, but the fat of the tail, and near the tail, is soft and greasy. The same difference is found in the fat taken from different parts of beef—say in a roast sirloin of beef. When cold, the under fat is hard, the upper fat soft. Now this tells that there are different kinds of fat, and we may justly conclude that there must be some difference in their composition. Fat is chemically "a salt," for it is made up of an acid and base. Now, inasmuch as it is the product of animal life, it is called an organic salt.

We will first consider the hard fat. The acid constituent of it is called stearic acid, and the base is called glycerile. It is found to occur largely in mutton suet; but with it are other fats in small quantities—viz., oleine, or oleic acid and glycerile, and margarine, or margaric acid and glycerile. If mutton suet be heated with ten times its volume of ether, and be then allowed to cool, white scaly crystals will be formed. These are nearly pure stearine; the other fatty bodies present in the suet remain in solution. These scales can be dried by pressing them between folds of blotting-paper, and can be rendered quite pure by recrystallisation. Margarine occurs in goose-grease and in olive oil; it is also a constituent of human fat. It can be obtained by submitting the fat to a temperature of zero (centigrade). A portion of it solidifies; this should be pressed. It can be purified by dissolving it in boiling alcohol, and allowing it to crystallise. Oleine does not solidify at zero (centigrade); it, by the action of the air, becomes slowly oxidised; it can be separated from the other fats by allowing them to crystallise out first from the alcoholic solution of the oil. After their removal the alcohol may be evaporated, and the oleine will be left. There are differences, however, in oleine obtained from different kinds of oil, but these hardly concern us in this paper.

Oleic acid is a large constituent of the softer fats, and of oils. Stearine is a salt like carbonate of lime; it contains an acid and a base; the acid is stearic and the base glycerile, and when acted upon by suitable substances can be decomposed. If some salad oil be mixed and shaken up with water it will be found to be suspended in the water in the form of small globules, but on standing the oil will float on the top, and there will be a complete division of the two liquids. Oil does not mix with or dissolve in water. Put some salad oil into a test-tube with three or four times its volume of water, and try this; afterwards drop into the mixture a small quantity of a solution of caustic soda or potash, and then shake up again. This time the liquid will become milky, and will remain so. Now, if this mixture be boiled for some time in a beaker glass, the water being supplied as it evaporates, the whole of the oil will be changed in its nature—that is, it will be decomposed. The same experiment can be made with chopped-up suet and caustic soda. The oil was first suggested because the changes are more rapidly apparent. Here, if suet be used, the change which takes place is as follows:—The caustic soda expels the organic base glycerile, which takes up water, and becomes the well-known substance, glycerine, and, with the stearic acid, forms sodic stearate. Here we have, then, a salt formed of an organic acid, and an inorganic base. This is soluble in water, and is really soap—soda soap. If caustic potash had been used a similar result would have followed, only the soap would have had somewhat different properties. Still it would be soluble in water. Suppose, if instead of using either of these alkalies, we were to boil some oil with lime and water, a different kind of soap would be formed, which is not soluble in water. Take a large Berlin dish—a saucepan will do—put into it some oil, powdered slaked lime—*i.e.*, lime which has been wetted with water—and some water; then let it boil for some hours; stir it constantly; in time a solid

sticky mass will be formed; and when the action is completed lime soap will be made, and in the water will be the glycerine. Here the lime takes the place of the glycerile, and lime oleate is formed, because the fatty acid in oil is not stearic, but oleic acid; and the glycerile becomes glycerine in the same way as in the former experiment.

It is clear, then, that fats, oils, and solid fats are salts, and that they can be decomposed, part of their organic constituents being replaced by inorganic substances, and that soaps are the result, and that soaps, too, are salts. Before proceeding to a description of the manufacture of soap it will be well to describe the method of making glycerine. Glycerine is sometimes obtained by boiling litharge, *i.e.*, protoxide of lead, with fatty matter in the presence of water. The experiment can easily be performed. It requires that oxide of lead should be substituted in the last experiment for lime, when lead plaster will be formed, which is an insoluble soap, and the glycerine will remain in solution in the water. If the glycerine is wanted pure, sulphuretted hydrogen can be passed into the solution, to precipitate any lead in solution, and after filtering, the liquid may be evaporated in a water bath; that is, in a vessel standing in boiling water, or over it, so as to drive off excess of water, and the glycerine will be obtained as a thick, sweet liquid; hence its name, from a Greek word meaning sweet. Glycerine dissolves freely in water and in alcohol. It is the material from which is made that dangerous explosive, nitro-glycerine. In order to obtain it, glycerine is mixed with nitric acid and oil of vitriol. The mixture must be kept cool. The ordinary applications of glycerine are generally well known, except that, perhaps, it is not so well known that it has antiseptic properties, and can be used for the preservation of food. Glycerine is manufactured on the large scale by the action of superheated steam on fats. The fat is heated in a still to a temperature of about 300° F., and superheated steam is injected. The fats are decomposed, and the glycerine is distilled over with the steam. It is obtained as a thick colourless liquid. The fatty acids, also, are obtained in this way. They are very pure and white, and are used in the manufacture of candles.

It will be now understood that soap is a chemical compound, consisting of several of the fatty acids united with soda or potash. The hard soaps contain soda and the soft soaps potash. The chemical symbols used to express the composition of the various fats are rather complicated, therefore it is perhaps better to omit them here; but the following may serve to express in a simple and clear manner the changes which take place. Stearine—it may be explained—is a combination of stearic acid with the oxide of glycerile:—

Suet fat.
Stearine.

Soap	Stearic acid	Oxide of glycerile	Hydrated oxide of glycerile, or glycerine.
	Sodic oxide	Water	

Caustic soda.

Reading the lines in the horizontal direction shows the names and proximate composition of the substances used — stearine and caustic soda. The dotted line shows the changes which have taken place, and the name of each product formed is given at either end. It has been said that hard soaps are made with soda. Some hard soaps are harder than others, and this depends upon the temperature at which the fats melt. If much oleic acid be present the soap will be softer than when there is a large excess of stearic acid. Many different kinds of fat are used in soap making—tallow, palm oil, refuse fat from the kitchens, train oil and other fish oils, cocoa-nut oil, the grease which is got out of bones, linseed and poppy oil, olive oil, almond and rape oil, and resin. Resin dissolves in alkalies, and so mixes in certain kinds of soap. The soaps which are compounded of soda and linseed and other drying oils are soft. The drying oils are those which are used by painters on account of the property they have of becoming oxidised, and of so forming a resinous compound which fastens and protects colours used in painting. Other oils when oxidised do not harden, but become rancid, such as olive or salad oil. Carbonate of soda does not decompose fats, therefore the soda must be used in the caustic state. To obtain this the soap-maker boils a solution of carbonate of soda with lime. The lime takes away the carbonic acid, which forms insoluble carbonate of lime, and the caustic soda remains in the solution. It is necessary that the solution of carbonate of soda be weak, otherwise its complete decomposition by the lime would not be effected, and any undecomposed carbonate of soda which remained would be useless in soap-making. The solutions of caustic soda employed are called "leys," and the strength of the solution of carbonate employed is indicated by the specific gravity 1·090. After the "leys" are thus prepared, the first thing done is the charging the soap-pans with oil or fat, and then are added the weak leys of a specific

gravity of 1·050. The soap-pans are made of iron plates, fastened with rivets. They are of various sizes, some being fourteen or fifteen feet in diameter, and of the same depth. Often as much as twenty to thirty tons are made at a time. When the pan is charged, it can be heated in the most convenient way, either by external heat or by means of steam injected through pipes with holes in them, or by means of a coil of pipe through which steam is continually passing. If the steam be injected, it acts as a stirrer, and keeps the contents of the pan in motion. In time the solution assumes a thick milky appearance, such as that which would be seen if the first experiment described were performed. If some of this be taken out and be allowed to cool it remains unchanged, and the water does not separate out from it. Sometimes a weaker solution of caustic soda is added, if the action does not go on favourably, as the saponification does not at first go on as well with strong as with weak solutions. After a time stronger solutions are added. Prior to this addition the solution has lost its alkaline reaction, and this is tested by the tongue. The boiling is continued, and then more fat is added, and sometimes some resin. It is desirable that during this period there should not be an excess of alkali. When the desired quantity is in the pan, and the operation completed, common salt is added. Salt abstracts the water from the mixture, and in this way the soap is separated out, and this soap contains a definite quantity of water combined with it. The soap now rises to the surface, and the water and glycerine remain in the liquid below, and these are drawn off and thrown away after the mass has stood for some hours. The soap in this condition is now treated with a weak solution of caustic soda, and they are boiled together. Now, if necessary, may be added more fat; but the mixture is made to have a strongly alkaline reaction. Salt is again added, to separate the soap from its solution, and it is boiled for some time, the solution being kept alkaline. After a few hours the soap is removed and placed in suitable iron frames, where it is allowed to remain until it is solid, and it is then cut into bars by wires, the under part, which is soft, being scraped off and used in future operations. When resin is used, before the framing operation the soap is melted with water and boiled. The soap dissolves, and forms a compound which is even in its composition. After standing for two or three days the soap separates, and has a composition of about 65 per cent. of fatty acids, 6·5 of soda, and 28·5 of water. The residual liquid which lies beneath the soap is called the "nigre." The soap is then put into frames to harden. The nigre is used in making mottled soap. Resin is used in the manufacture of yellow soap: it is added usually after the saponification of the fat is effected; the proportion in which it is used is about one-third of the tallow. Resin soap contains generally about 60 per cent. of grease and resin, 6 of soda, and 34 of water; but its composition is somewhat variable.

In making mottled soap, soda containing sulphides is employed, but in white curd, soda free from sulphides is used. When the soap is nearly finished it is watered with a rose watering-pot with a strong solution of alkali, containing sulphides. In some countries a dilute solution of sulphate of iron is used. The sulphate is decomposed by the alkali, and ferrous oxide is set free. This passes through various stages of oxidation, and so produces tints varying from a blue-green to red or brown. When the oxide becomes red it gives the colour which is called "manteau Isabelle." The soap paste is broken up so that the mottling liquid can trickle into the cracks formed. The workman pushes his rake through the crust of soap, and moves it up and down vertically. The mottled appearance resulting from the presence of oxide of iron, and some insoluble iron soap, can be got rid of by dissolving the soap, and allowing the heavy metallic oxides to sink to the bottom. Mottled soap contains a definite quantity of water, and hence it is prized because the water in it cannot be excessive, for it is, of course, the object of the manufacturer to make his soap hold as much water as possible. Imitations of real mottled soap are often made by the addition to the soap in the soft state, when it is sufficiently hard, of colouring matters. This soap, however, does not contain a definite quantity of water.

Those who have read the paper on "Flint"* will remember that when flints are boiled under pressure with caustic soda they are dissolved, and a thick sticky liquid is the result. This liquid is a solution of silicate of soda. It has strange properties, and among them it acts as a soap. It is a powerful detergent. However, when used for washing the hands, it makes the skin very rough afterwards, although, when diluted with the washing water, it has a soft and pleasant feel. Silicate of soda is used in the manufacture of certain soaps; it readily incorporates itself with soap when stirred up with it. If soluble silicate be boiled with fats

* "Science for All," Vol. IV., p. 346.

or resin, some of the alkali in it unites with these substances, and in this way a soap can be made which is not so powerful in its detergent properties as when the silicate is combined with ordinary soaps. The quantity of free alkali in these soaps can be reduced by the action on them of one of the mineral acids, or by carbonic or sulphurous acid gases. The last two are always passed into the liquid soap in the gaseous form. Silicated soaps are cheap, and for rough purposes very useful, as they cleanse very rapidly. Silicate of soda to be employed in soap making is sometimes prepared by a very interesting process. Common salt is heated to a very high temperature until it is vaporised. In this state it is brought into contact with steam at a very high temperature in a suitable fire-brick chamber. A double decomposition ensues, which is represented by the following equation :—

$$\underset{\text{Common Salt.}}{2\,(NaCl)} + \underset{\text{Steam.}}{H_2O} = \underset{\text{Sodic Oxide.}}{Na_2O} + \underset{\text{Hydrochloric Acid.}}{2\,(HCl)}\ ;$$

but as the temperature falls a reverse action takes place, the hydrochloric acid unites again with the sodic oxide, and the original bodies, salt and water, are formed. To prevent this, silica, in the form of porous lumps, is placed in the hot chamber in which the vaporised salt and steam meet together, the sodic oxide unites with the silica or silicic acid forming sodic silicate, and the hydrochloric acid remains free. When the hydrochloric acid is condensed or dissolved in water, a small quantity of silicic acid, resulting from the decomposition of some of the silicate of soda by its action, will be dissolved in it. Some soaps which are named silicious soaps, only contain silica ground up, and in mechanical mixture with them. Here the silica is of no use whatever, it is simply an adulterating substance.

Soft soap differs in many important respects from hard soap. When hard soap is dried, it contains a certain definite quantity of water which is held in a sort of chemical combination with it. It is a water of hydration. This is not the case with soft soaps. The water which they take up and retain is simply held as a mixture, and when there is in them a slight excess of alkali, they take up water from the air, or deliquesce, as it is called. The fats from which soft soaps are made are generally oils, such as rape, and also fish oils. In making these soaps a ley of caustic potash has to be prepared. This is done by boiling the carbonate with lime until the ley is perfectly caustic. They are made of two different strengths, one 1·05 specific gravity, the other 1·20, and sometimes 1·25. They are made from the potashes of commerce, which contain about 60 per cent. of real alkali. The oils employed are heated in a suitable pan just to the boiling point of water. The weak ley is then introduced, and the mixture is heated till it boils. More oil is then put in, also more ley, and this is done alternately till all the oil required is used up. A gentle boiling is now continued, and strong ley is added until the action is quite completed. At first there is frothing. This at last subsides, and the mass becomes transparent and thickens. The soap is then applied to the tongue, and, if it is not acrid, then a portion is taken out and put on a glass plate. If it is transparent and perfectly clear then the soap is made. Often a small quantity of tallow is added, and this causes whitish grains to form in the mass, giving it the appearance of the inside of a fig. It is therefore called "figging." M. Thenard gives the composition of soft soap at 9·5 potash, 44·0 oil, 46·5 water. London soft soap yields 8·5 potash, oil and tallow 45·0, water 46·5.

What is called "marine soap" is made from cocoa-nut oil. Cocoa-nut oil saponifies differently from other oils and fats. A very strong soda ley is used in its preparation, of a specific gravity 1·16. Great care is taken to thoroughly purify it. The soap hardens very quickly, and shows no signs of forming a curd. It is white and semi-transparent. The odour is unpleasant. Cocoa-nut oil soap combines with more water than ordinary tallow soap; it can therefore be adulterated to a considerable extent with water. It forms a good lather. Cocoa-nut soap is not separated like tallow soap by common salt unless this substance be used in large quantities, therefore it is possible to wash with it in sea water. It is accordingly called marine soap.

"Palm oil soap" is made in the same way as other soap. It is prepared from palm oil with soda. It is yellow in colour, and has a very agreeable smell. Generally palm oil is mixed with some other fat. About 3 lbs. of palm oil to 1 lb. of tallow make a good soap. An inferior soap, called demi-palm, is made with 1 lb. of palm oil and 4 lbs. of tallow. Palm oil can be bleached so as to afford a white soap. Palm soap is very soft and pleasant, and these properties, combined with its agreeable odour, make it a very favourite soap. The soaps which are used for the toilet are generally made up by perfumers. The base

is ordinary curd soap, but very pure. This curd soap is refined by cutting it into shavings. It is then melted over a water bath with rose-water and orange-flower and some salt; 24 lbs. of soap are mixed with four pints of rose-water, and the same quantity of orange-flower water, and about two handfuls of salt. The next day the soap, when cold, is cut into pieces and dried in a shady place; then melted again in the same quantity of rose and orange-flower water, and is strained, cooled, and dried. These operations destroy the bad smell of the soap. It is then scented according to taste, and is moulded and pressed in the desired forms. Most fats require to be boiled with the alkali in order to ensure perfect saponification, but lard, beef marrow, and oil of sweet almonds can be saponified by shaking them up with caustic soda without heat. Some soaps for toilet purposes are made in this way, and are dried, scented, and pressed into cakes. Almost any perfumes may be used with soap. They are usually coloured with blue ultramarine (artificial) and with vermilion. The brown tint is produced with an alkaline solution of burnt sugar. Soft shaving soap is made by beating up 50 lbs. of lard with 75 lbs. of caustic potash ley, 17° (Beaume). Glycerine is sometimes mixed with soap before it is put into the frames. This makes a good toilet soap, and produces a softening effect on the skin. Transparent soap is made by first drying ordinary soap thoroughly; then it is dissolved in alcohol with the aid of heat. The solution should be left to stand for some time, that all impurities may settle down. When this has occurred, the alcohol is distilled off, and the residual transparent soap is allowed to become solid in moulds. Marseilles and Castile soaps are very good and pure. They are made with soda and a very good sort of olive oil. They are very hard and free from grease. Every one must have noticed how difficult it is to wash in some waters: the soap used does not form a lather, but sticks about the hands. This is because there is lime or magnesia or both, in the water, and these substances decompose the soap. The lime, or magnesia, takes the place of the soda, and forms lime or magnesia soaps, both of which are insoluble in water. If a person continues rubbing the soap for some time, he will precipitate all the lime in the water, and then he will be able to form a lather. Lime exists in two different forms in water; in the chalk districts it is dissolved as carbonate by excess of carbonic acid. Chalk, which is carbonate of lime, is absolutely insoluble in water, but lime, which is calcic oxide, or chalk without the carbonic acid, is to some extent soluble in water. If carbonic acid gas be passed into lime-water in a test-tube, a white precipitate will immediately appear, and this will become thicker up to a certain point; then, as the carbonic acid continues to be passed in, the white precipitate will be dissolved, and the liquid will become clear. The white precipitate is carbonate of lime, chemically the same as chalk, and the excess of carbonic acid dissolves it up. An apparatus for performing this experiment is given at page 348, Vol. IV. In the receiver C should be put the lime water. If this clear liquid be boiled, or rather a part of it, the white precipitate will reappear, because boiling will drive off the excess of carbonic acid, which holds the carbonate of lime in solution, and therefore it will be precipitated. If, then, water be rendered hard by carbonate of lime, it can be made soft by boiling it for some time, and allowing it to settle. If another portion of the clear solution be put into another test-tube, and some lime water be added to it, the white precipitate will reappear, because the lime in the lime water will take away the excess of carbonic acid, and will form with it carbonate of lime, and it, with the carbonate of lime dissolved in the water by the carbonic acid, will be precipitated. And this is another way of making such hard water soft. Put the hard water for practical purposes into a pan or tub, add to it a small quantity of quick-lime, and stir it well; leave it to settle, and the chalk dissolved in it will be precipitated, and it will be made soft. Lime also exists in water in the form of sulphate. As sulphate of lime is somewhat soluble in water, the only way to get rid of this, so as to render the water fit to be used for washing purposes, is to add a sufficient quantity of carbonate of soda to throw down the lime as carbonate.

$$\underset{\text{Sulphate of Lime.}}{CaSO_4} + \underset{\text{Carbonate of Soda.}}{Na_2CO_3} = \underset{\text{Carbonate of Lime.}}{CaCO_3} + \underset{\text{Sulphate of Soda.}}{Na_2SO_4}$$

It may be useful to mention that soap is employed for other purposes than washing. It is a somewhat important ingredient in the preparation of certain drugs, both for internal and external application. Soaps for medicinal purposes are specially and carefully prepared. They should have no greasy feel, and salts should not crystallise or effloresce on the surface. They should be hard and firm. They are sometimes used dissolved

in alcohol, with which they form a transparent but somewhat gelatinous solution: as they are decomposed by acids and neutral fats, care must be taken not to mix them with any of those substances with which they do not agree. Hard soap rubbed up with vegetable resins and balsams mixes well with them, and thus they become soluble in water, and so can be made up into pills, which have this advantage, that they can be dissolved in the stomach, whereas resins alone might pass unaffected through the intestines. It also renders unctuous and other animal substances soluble in water. It is used in making liniments and embrocations. Soap has also a slight aperient action: it is also a mild anti-acid, and is said to possess advantages over the alkalies given alone. It is also given in rheumatic affections, and in gout where swellings occur in the joints, and are called chalk-stones. It is supposed to dissolve these. There is no doubt at all but that it is very useful in external applications for bruises and sprains. It has also been administered with effect in cases of poisoning by corrosive substances, such as oil of vitriol, aquafortis, and corrosive sublimate. Soap is also used to test the hardness of water. It has just been mentioned that when soap comes in contact with lime in water it is decomposed, stearate of lime, or lime-soap, being formed. In order to test the hardness of any sample of water, that is, to find out how much lime is held in solution in it, a solution of Castile soap in alcohol is employed. What is called a standard solution of soap is made; that is, a certain known weight of soap is dissolved in a certain weight or measure of alcohol. A given measure of the water to be tested is put into a bottle, and some of the solution of soap is dropped in; the stopper is placed in the bottle, which is well shaken. If no permanent froth or lather is formed on the surface of the water more of the soap solution is added, and the mixture is again shaken, and the operation is repeated till a permanent lather is obtained. It is then ascertained how much of the alcoholic solution has been used, and this tells the quantity of soap decomposed, and from this is calculated the quantity of lime present which decomposed it.

It was in the year 1524 that soap was first manufactured in London. Before that time soap was made principally abroad. Some, however, was made at Bristol. This was grey in colour, speckled with white; it was very cheap. Its price was a penny a pound. There was also a black soap in use which was still cheaper. For many years nothing was known of the chemical composition of soap, or, at least, nothing accurate. A little more than one hundred years ago the true principles of chemical science were not understood, and it was not till after the discovery of oxygen that we can date the commencement of our present knowledge. In 1813 M. Chevreul, a noted French chemist, published the results of his investigations into the compositions of oil and fat, and the works of this eminent man remain to the present day authorities on this subject. Chevreul has done as much as any other chemist to advance our knowledge, to improve our methods of investigation and analysis, and to enable us to classify bodies, and we cannot fail to admire the acuteness and perseverance of a man who had to discover methods which, in his time, did not exist, and who therefore, unlike modern chemists, had to strike out for himself an entirely new line of investigation. Possessing, as we do, a knowledge which simplifies research, and enables us to apply our scientific knowledge to useful applications, it is surely worth the while of every one, whose disposition leads him to scientific studies, to follow out earnestly his instincts in the direction of chemistry. Soap, and other of the useful substances, whose composition depends upon chemical changes, were found out empirically, and it was left for us in later days to explain the principles on which their manufacture was founded, and to improve the processes of that manufacture. Now that the science of chemistry is better understood, and more generally and completely studied, chemists argue from their knowledge as to what ought to take place, and follow out their arguments to practical conclusions; or, in their laboratories, they observe certain things which occur, perhaps, by mere accident. They investigate them, and so find out processes which become eminently serviceable to mankind. The discovery of the coal-tar colours (p. 80) is an illustration of this, and no one can deny but that this discovery has conferred on society great benefits, and has been highly remunerative to those to whom we owe it. Surely such instances as this—and many others could be mentioned—ought to lead those who have a taste for science to do something more than make it a source of simple amusement.

HOW MOLECULES ARE MEASURED.

By Professor Josiah P. Cooke,

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In a previous paper (p. 245) we described the method by which the lengths of the waves of light are measured. In this paper we propose to show how the values thus obtained may be applied to measuring the size of the molecules of matter.

Does a material body completely fill the space it seems to occupy? or is it an aggregate of small units separated by spaces? and if the latter, what are the dimensions of these units? These are the questions we are to discuss and the standard of minute measure we have established will greatly aid us in our investigation. First, we will notice certain general considerations, which, although they may not help us in measuring the size of the integrant particles of matter, have an important bearing on the question of their reality.

When water is heated to 212° Fahrenheit it boils, and changes into steam one cubic inch of water, yielding a little over one cubic foot of steam. Now, two suppositions are possible as modes of explaining this change. The first is, that in expanding, the water becomes diffused through the cubic foot, so as to fill the space completely with the substance we call water, the resulting mass of steam being absolutely homogeneous, so that there is no space within the cubic foot, however minute, which does not contain its proportion of water. The second is that the cubic inch of water consists of a definite number of particles, which, in the process of boiling, are simply separated to a greater distance. Hence the steam is not absolutely homogeneous, for, if we consider spaces sufficiently minute, we can distinguish between such as contain a particle of water and those which lie between the particles. Now, the following experiment indicates that the last is the true explanation of the change of volume.

We take a glass globe, which we will assume has the capacity of a cubic foot. Into this globe we pour one cubic inch of water, and maintain the vessel at the temperature of boiling water. After a short time the water will have evaporated, and filled the globe with ordinary steam, which we confine by closing the stop-cock at the mouth. If, now, that cubic foot of space is really packed close with the material we call water, if there is no break in the continuity of the aqueous mass, we should expect that the steam would fill the space, to the exclusion of everything else, or, at least, would fill it with a certain degree of energy which must be overcome before any other vapour could be forced in. But what are the facts? If the stop-cock is so arranged that we can introduce into the globe any liquid on which we desire to experiment, without otherwise opening the vessel, we shall find on running in alcohol, for example, that this volatile liquid will freely evaporate into the space assumed to be filled with steam, and if we make comparative experiments with the vessels filled with air, and also after the air has been exhausted by an air-pump, the remarkable fact will appear that precisely the same amount of alcohol will evaporate into the space, whether "filled" with steam or filled with air, or entirely empty, provided only the temperature is kept the same in all cases. And what is still more singular, if, after the space is saturated with alcohol vapour, we introduce benzine, the same phenomena will be repeated. The benzine will evaporate, and fill the space with its vapour, and the globe will hold just as much benzine vapour as if no other substance were present; and so we might go on, as far as we know, indefinitely. There is here no chemical union between the several vapours, and we cannot, in any sense, regard the space as filled with a compound of them. It contains all the vapours at the same time, each acting as if it were the sole occupant of the space.

Evidently, then, no vapour completely fills the space which it occupies, although equally distributed through it, and we can give no satisfactory explanation of the phenomena of evaporation, except on the assumption that each substance is an aggregate of particles or units which, by the action of heat, become widely separated from each other, leaving between them large spaces, within which the particles of an almost indefinite number of other vapours may find places. These units we call *molecules*, a Latin diminutive, which means *little masses*. We now pass to another class of facts illustrating the same point.

The three liquids—water, alcohol, and ether—are expanded by heat, like other forms of matter, but there is a very great difference in the amount

of their expansion for the same increase of temperature. Alcohol expands about three times as much as water, and ether more than alcohol. What is true of these three liquids is true, in general, of all liquids. Each has its own rate of expansion, and the amount in any case does not appear to depend on any peculiar physical state or condition, but is connected with the chemical nature of the substance, although in what way we are as yet wholly ignorant. There is, of course, nothing remarkable in this, for why should we not expect that the rate of expansion would differ with different substances? But the remarkable point is yet to be stated. Heat these liquids to any constant temperature above the boiling-point of water, and we shall convert all three substances into vapours. Study, now, the rate of expansion of these aeriform bodies, and it will appear that, although they expand far more rapidly than in the liquid state, the influence of the nature of the substance on the phenomenon has wholly disappeared; and that in the state of gas these substances, and in general all substances, expand at the same rate under like conditions.

Why is this difference between the two states of matter? If the material fills space as completely in the aeriform as it does in the liquid condition, then we cannot conceive why the nature of the substance should not have the same influence on the phenomena of expansion in both cases. If, however, matter is an aggregate of isolated molecules, which, while comparatively close together in the liquid state, become widely separated when the liquids are converted into vapour, then it is obvious that the action of the particles on each other, which might be considerable in the first state, would become less and less as the particles were separated, until at last it was inappreciable; and if further, as Avogadro's law assumes, the number of these molecules in a given space is the same for all gases and vapours under the same conditions, then it is equally obvious that, there being no action between the particles, all vapours may be regarded as aggregates of the same number of isolated particles similarly placed, and we should expect that the action of heat on such similar masses would be the same.

There are many other phenomena which, like those we have described, almost force upon us the conviction that the various forms of matter we see around us do not completely fill the volumes which they appear to occupy, but consist of isolated particles separated by comparatively wide intervals.

But we have not space for more details, and must pass on to consider facts which enable us to form some conception of the size of the molecules, whose existence, we must now assume, has been made evident.

When a beam of light passes from the air into a denser medium, for example, into water (and we have taken water as the basis of our illustration in this paper, not only because this substance is so familiar, but also because it is so well adapted to the purpose), the beam is bent from its rectilinear path. And not only is the beam bent as a whole, but the different colour-giving rays of which it consists are bent to a slightly different extent, so that after entering the water they diverge from each other. The violet rays, with their short waves, are bent more than the red rays, with their comparatively long waves; and to an observer, immersed in the liquid, the refraction at the surface would produce, under all oblique incidence of the light, effects similar, although of less degree, to those we see on looking through a prism. To such a sub-aqueous observer, the images of objects above the surface, if not on the vertical line, would appear bounded by blue and red fringes, and the image of an illuminated slit would be extended in a short spectrum.

According to the undulatory theory, this bending or refraction of a luminous beam results from the lessening of the velocity of the onward motion of the waves of light on entering a denser medium, and the dispersion of the various colour-giving rays is explained by the fact that the velocities of these different rays are affected to a somewhat unequal extent, depending on the length of their waves. The ratio of the velocity of light in air to its velocity in another medium is called the index of refraction in that medium, and in the case of water this value is 1·335, varying, however, between 1·3309 and 1·3442 for the extreme rays of the spectrum, marked by the Fraunhofer lines B and H. Hence, while the velocity of light through the celestial spaces and also through air is 186,380 miles per second for all rays, whatever the wave-length (at least we have been able to detect no difference), the velocity in water varies between 140,040 miles per second for the red rays corresponding with the line B, to 138,660 miles per second for the violet rays corresponding with the line H.

It must further be stated that according to our theory the light-producing waves spread, not through any medium cognisable to our senses, but

through a wholly impalpable medium, called the luminiferous ether, which is supposed to pervade the whole material creation, the interiors of the densest bodies, as well as the interstellar spaces. To this medium the theory ascribes the most remarkable qualities. It has a tenuity vastly greater than that of hydrogen gas, the lightest form of matter otherwise known; but at the same time, its parts are as inflexibly held in a fixed position as are those of a bar of steel. The earth, or any other body, in moving through the ether, does not displace it as a bird displaces the air or a fish displaces the water, but the ultimate particles of these bodies move independently through a medium which surrounds them individually, in the same sense that the air surrounds the bird, or the water the fish. They move through the ether while maintaining their relations to the body of which they are a part, in the same sense that the members of the solar system have a common motion through space while preserving their mutual relations to each other. Indeed, the ether is the only fixed material of nature, and material bodies are simply systems of atoms which move and toss in this medium.

Remembering that the molecules must be far smaller than the waves of light (for if not they would be visible under powerful microscopes), it will be seen that these waves, in passing through a transparent body, do not pass between the molecules, but go over and engulf them, the molecules tossing to and fro as the waves pass on; and although these molecules may clog, or, as in the case of opaque bodies, wholly deaden the wave motion, they do not alter its essential character. The effect of material molecules on waves of light may be rudely compared with that of the rushes of a marsh, overflowed by the tide, on waves of water. They also, when tossed by the waves, tend to deaden their motion. But without pushing this analogy, which would soon fail on account of the essential difference between waves of water and waves of light, it can readily be seen that the same molecules could not produce an unequal effect on waves, which differ from each other in length at most only as one to two, if the size of the molecules were vastly less than the size of the waves. It requires no profound science to see that, if the molecules bore no larger relation to the waves of light than do particles of sawdust in the waters of an estuary to the waves that roll in from the ocean, the difference of effect produced by such a slight obstruction would not be perceptibly altered by a change of one-half in the size of the waves. And, on the other hand, if the molecules were comparable with logs of wood in such an estuary, the difference of effect might be marked. Moreover, knowing as we do, very accurately, the retardation of waves of measured lengths in various media, it might seem as if we could calculate the size of the molecules which caused the obstruction in each case. But unfortunately such are the difficulties of the problem, and so uncertain are some of the data it involves, that as yet we have not been able to solve it satisfactorily, although it has engaged the attention of mathematicians of the greatest power. Reasoning on this basis alone, we can as yet form only a very rough estimate of the size of the molecules of matter, but, assuming the truth of the general theory, we can say with a very considerable degree of certainty that the average distance between the centres of two neighbouring molecules of water must be at least a thousand times smaller, and, on the other hand, that it cannot be a hundred thousand times smaller, than the mean length of the luminous waves of light. This, of course, is a very rough estimate, but still it establishes the order of the magnitudes with which we are dealing, and that is a great deal. Let us next study some other phenomena connected also with water, which will enable us to make a still closer approximation to the values we are seeking.

From water, with which a little soap and glycerine have been mixed, films can be obtained of very great tenuity, whose thickness, measured by the waves of light, gives us an obvious limit to the possible size of the molecules on one side, while the laws of capillary action to which these phenomena conform, enable us to fix an equally close limit on the other side.

The familiar soap-bubble, already described in some of its features,* is usually regarded as a child's toy, though it presents phenomena worthy of the attention of the philosopher. Those gorgeous colours which float over the bubble as the film grows thin, are an effect of the interference of the rays of light reflected from its two surfaces. A portion of every incident beam is reflected from the outer surface, but another portion passes through the film, and is reflected from the inner surface; and it is evident that the path of the last is longer than that of the first by just twice the thickness of the film. Moreover, owing to relations which it would take too long to discuss here, the rays reflected from the inner surface lose one-half a wave-length in the

* "A Soap Bubble:" "Science for All," Vol. III., p. 64.

very act of reflection. Hence, when these two portions of the reflected beam come into the same path again, there is more or less interference, and, if the retardation has been such that the crests of the red waves in one portion of the beam exactly fall over the troughs of the similar waves in the retarded portion, then the corresponding colour-giving rays are wholly destroyed. Moreover, in all other rays, where this relation, although not exact, is approached, the motion is deadened to a greater or less extent. The result is that, in general, about one-half of the coloured rays which the white light contains are deadened, and the reflected beam produces the impression of the compound colour, which results from the mingling of the rays not thus extinguished. The effect is not unlike that of coloured glass, which also, although in a different way, deadens the different coloured rays of white light unequally, and appears as if coloured by the rays which are transmitted.

As the thickness of the film of the soap-bubble varies, the colour changes; for as the amount of retardation diminishes with the thickness of the film, a different set of waves are deadened, and different colours disappear from the reflected light.

Although there is nothing more splendid of its kind than a large soap-bubble made with glycerine soap-suds,* the variation of the colour with the thickness can be better shown by forming the film in a less familiar although an equally simple way. For this purpose pour a little of the soap-solution into a shallow dish, and dip into it the open mouth of a common tumbler or wine-glass. By gently raising the glass it is easy to bring away a thin film covering the mouth; and if the glass is now held with the film vertical, so that the light from a window is reflected from the film to the eye, a succession of beautiful phenomena will be seen. The same brilliant hues are seen as on the soap-bubble, but they appear in regular bands crossing the film horizontally, and this we should naturally expect after what has been said; for the colour at any point depends on the thickness of the film, and since this is held in a vertical position, it is evident that the effect of gravity must be to stretch the liquid membrane, constantly thinning it out from the upper end. As the film becomes thinner and thinner, the bands of colour, which correspond to a definite thickness, move downwards, and are succeeded by others corresponding to a thinner condition of the film, which give place to still others in their turn. These colours are not simple colours; but for each point of the film they are, as we have seen, the results of the combination of the residual rays not deadened by the interference at that spot. The parti-colours result from the overlapping of bands of infinitely-varied tints, and in order to reduce the conditions to the simplest possible, we must use monochromatic light. The effect of a monochromatic light can be approximately obtained by holding before the eye a plate of green glass coloured by oxide of copper,

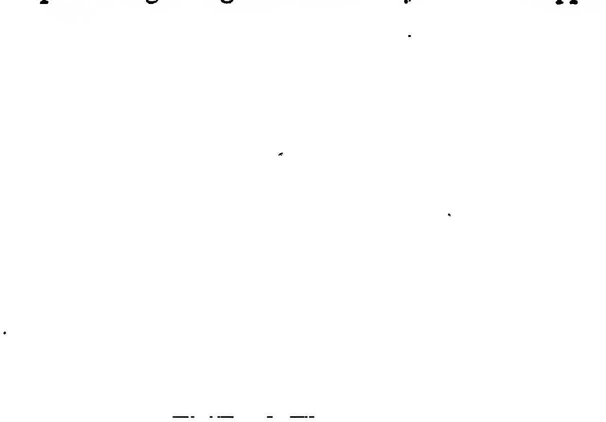

Fig. 1.—Showing Effect of a Monochromatic Light

when at once all the parti-colours vanish, and we have merely alternate green and dark bands as shown by Fig. 1.

These dark bands are evidently zones where the wave motions of this green light are deadened because the crests of the waves of one portion of the reflected beam fall full over the troughs of the waves of another portion, and since this relation must obtain whenever one ray gains any odd number of half wave-lengths on another, it is evident that the bands must be repeated as the thickness of the film increases; and if along the line of the first dark band the interference is caused by a difference of $\frac{1}{2}$ of a wave-length, along the line of the second band it is caused by $\frac{3}{2}$ of a wave-length, and so the succeeding bands mark a difference of $\frac{5}{2}$, $\frac{7}{2}$, $\frac{9}{2}$, $\frac{11}{2}$, &c., respectively.

As, however, we watch the bands which chase each other over the film, we notice that after a short time new bands cease to appear, and a uniform light tint spreads over the upper half of

* To make the best preparation, put into a quart bottle four ounces of the best white Castile soap (or, still better, pure palm oil soap), cut into thin shavings, and fill it up with cold *distilled* water. Shake well together until you get a saturated solution of soap, and allow the bottle to stand for some days at a uniform temperature. If the soap and water are both pure the solution will settle perfectly clear, leaving at most a slight opalescence. Decant now the clear solution, and to two volumes add one volume of concentrated glycerine.

the surface. Now comes the critical point in our experiment. If the film is in right condition this light tint will be succeeded by a grey tint, which appears in irregular patches at the upper border. But a moment after, all vanishes, for the film always breaks soon after the grey patches appear.

Remembering, now, that all rays reflected from the back surface of the film suffer a retardation of one-half a wave-length in the very act of reflection, the summary of the results of our discussion given in the following table will be readily understood:

Order of Bands.	Retardation of rays reflected from back surface of film.	Thickness of film in waves of green light $\frac{1}{50000}$ of an inch long.
Grey patches	$\frac{1}{2}$ wave-length	Less than $\frac{1}{4}$ wave-length
Light film	1 "	$\frac{1}{4}$ "
First dark band	$1\frac{1}{2}$ "	$\frac{1}{2}$ or $\frac{2}{4}$ "
First light band	2 "	$\frac{3}{4}$ "
Second dark band	$2\frac{1}{2}$ "	1 or $\frac{4}{4}$ "
Second light band	3 "	$\frac{5}{4}$ "
Third dark band	$3\frac{1}{2}$ "	$1\frac{1}{2}$ or $\frac{6}{4}$ "
Third light band	4 "	$\frac{7}{4}$ "
Fourth dark band	$4\frac{1}{2}$ "	2 or $\frac{8}{4}$ "
Fourth light band	5 "	$\frac{9}{4}$ "

The general result, then, is that the thickness of the light portion of the film above the first dark band is one-fourth of the length of a wave of green light, or about the $\frac{1}{200,000}$ of an inch. The grey patches must be still thinner, but how much thinner? That they cannot be a great deal thinner is evident from the fact that the film breaks so soon after the grey patches appear. On the other hand, twice the thickness of the film at these spots must be a very inconsiderable portion of the length of a wave of light, because the difference of phase of the rays reflected from the outer and inner surfaces is due wholly to the loss of a half wave-length in the last reflection. We thus reduce the question within narrow limits, and we cannot err greatly if we estimate the thickness of the dark patches at one-fortieth of a wave-length, or $\frac{1}{2,000,000}$ of an inch. Under favourable conditions there are certainly portions of the film as thin as this. Evidently we have now found a very definite outside limit to the size of the molecules of water. Their diameter cannot possibly be greater than the extreme limit of the thickness of this film. But this is an unnecessarily wide limit, for a very superficial consideration will show that even when most attenuated the film must be many molecules thick.

The tenacity of the film of a soap-bubble is determined by the mutual attraction of the molecules of which it consists. This cohesive force, as we call it, although very strong between neighbouring molecules, diminishes as the square of their distance increases, and soon becomes insensible. But compared with the size of the molecules the sphere of attraction is very large, and the cohesive attraction of each molecule of water must influence thousands of the molecules which surround it. The molecules within the sphere of attraction would naturally arrange themselves at the least possible distance from the centre of attraction, and thus take the form of a sphere, and the spherical form of the raindrop is a familiar illustration of this principle. In such a sphere the molecules are at the least possible distance from each other, and the force of cohesion is at its maximum. If we flatten out the sphere, we necessarily increase the total sum of the molecular distances, and to do this we must exert a sufficient force to overcome the cohesion, at least in part. Now precisely the same thing must result when, in blowing a soap-bubble, we diminish the thickness of the aqueous film. Compared with the small mass of water with which we are dealing, we must exert a large force to pull the particles apart. However, singular as it may seem, we are able to calculate the amount of this force, for it is precisely the same force which determines the rise of water in a capillary tube. The theory of capillary action is well understood, and these familiar phenomena give us the means of measuring what is called the *surface tension* of a liquid film. With the data thus obtained we can readily calculate how great a force would be required to stretch a film of water to any extent, for example, until its thickness was reduced to the $\frac{1}{500,000,000}$ of an inch. Now, we also know, and with great accuracy, the amount of heat which is required to part the molecules of water, and convert the liquid into steam. We further know with equal certainty the mechanical equivalent of heat, that is, the amount of mechanical energy corresponding to a given amount of heat. We therefore know how much mechanical energy is required to pull apart the molecules of one grain of liquid water, and it appears that the force required to do this work is no greater than, according to the theory of capillary action, is required to reduce the thickness of a film of water to the $\frac{1}{500,000,000}$ of an inch. It is therefore probable that before such a degree of tenuity could be attained, a point would be reached where the film had a thickness of a single molecule and that in stretching it further we should not reduce its thickness, but merely draw the molecules

wholly apart, and thus completely overcoming the cohesion, which determines the liquid condition of water, and gives strength to the film, convert the liquid into steam.

There are many other physical phenomena which point to a similar limit, and unless there is some fallacy in our reasoning, this limit would be reached at about the $\frac{1}{500,000,000}$ of an inch. Moreover, it is worthy of notice that all these phenomena point to very nearly the same limit. Sir William Thomson, from a comparison of all these phenomena, has estimated the limits as between the $\frac{1}{250,000,000}$ and the $\frac{1}{5,000,000,000}$ of an inch, and in order to give some conception of the degree of coarse-grainedness, as he calls it, thus indicated, he has said that if we conceive a sphere of water as large as a pea magnified to the size of the earth, each molecule being magnified to the same extent, the magnified structure would be coarser grained than a heap of small lead shots, but less coarse-grained than a heap of cricket balls.

These considerations will show how definite the idea of the molecule has become in the mind of the physicist. It is no longer a metaphysical abstraction, but a reality, about which he reasons as successfully as he does about the stars. He no longer connects with this term the ideas of infinite hardness, absolute rigidity, and other incredible assumptions which formerly brought the idea of a limited divisibility into disrepute. His molecules are definite masses of matter, exceedingly small, but still not immeasurable, and they are the points of application to which he traces the action of the forces with which he has to deal. These molecules are to the physicist real magnitudes, which are no farther removed from our ordinary experience on one side than are the magnitudes of astronomy on the other. In regard to their properties and relations we have certain definite knowledge, and there we rest until more knowledge has been obtained. The old metaphysical question in regard to the infinite divisibility of matter has nothing to do with the present conception. The molecule is a unit in the same sense that the earth is a unit. The geologist tears the earth to pieces, and in like manner the chemist deals with the molecules; but to the astronomer the earth is a unit, and so is the molecule to the physicist. Chemistry begins where physics end. To the physicist the molecules are the points of application of those forces which determine or modify the physical condition of bodies; and he defines molecules as the small particles of matter which, under the influence of these forces, act as units; or he may prefer to define molecules as those small particles of bodies which are not subdivided when the state of aggregation is changed by heat. To the chemist, on the other hand, the molecules determine those differences which distinguish substances. In the molecules the qualities of a substance reside. A lump of sugar, for example, has the qualities which we associate with that name, because it is an aggregate of molecules which have those qualities. The molecule of sugar is simply the smallest possible lump of sugar. We can divide or break up this molecule, but then we decompose the sugar, and a chemical change results. Starting with the different molecules, in which the qualities of his preparations inhere, the chemist finds that those molecules may be subdivided into still simpler units, which are the atoms or chemical elements of nature; and he seeks to investigate the structure of the molecules. He has devised symbols, with many of which the reader is doubtless already well acquainted, to represent this structure, and to show how the qualities and chemical relations of substances are determined by the nature and mode of grouping of the elementary atoms of which these molecules consist. But it would require a paper quite as long as the present one to illustrate these chemical conceptions; it is enough if, in this paper, we have shown that molecules are real magnitudes, or—to use the words of Sir William Thomson—"pieces of matter of measurable dimensions, with shape, motion, and laws of action, intelligible subjects of scientific investigation."

BREATH AND BREATHING.

By Andrew Wilson, Ph.D., F.L.S., etc.,

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THAT our chests rise and fall some fifteen or sixteen times a minute, and that we take air into our lungs and give air out of these organs, is a kind of truism which hardly needs mention to ensure the tacit approval of ordinary observation. But, at the same time, the observation is one which, like many others, settles down into an unexplained stolidity, because of its familiarity. The more familiar any object or process is, the less likely are we to trouble ourselves about its explanation or meaning. There are thousands of interesting facts concerning the common animals and plants by which we are surrounded, that remain unknown and unsought because the objects in question are so common. There are multitudes of facts about ourselves which never form part of the knowledge of thousands, because these thousands regard their own vital processes either with the familiarity that gives origin to contempt, or with the idea that their personal history, as living beings, is too complicated for ordinary comprehension. There is, however, no greater mistake. A large proportion of the facts of human life may be successfully studied by all who possess the common patience to undertake an easy and at the same time interesting study. Further, if we reflect that the preservation of health and the prolongation of life are results that follow from an appreciation of the simple details of natural science, the absolute value of such knowledge is not easy to overrate.

These remarks hold especially true of such a subject as that which relates itself to a function so intimately connected with the preservation of animal life of all kinds, as does the function of breathing. If we trace this function upwards in the scale of animal life, we shall find it to commence, like other actions of living beings, in a very ill-defined and general way. In the lowest animals the general *protoplasm* of the body, which we have seen to be capable of carrying on all the functions of life, must itself perform this function. As we advance upwards in the scale, we discover that as new organs and parts become added to the simpler possessions of humble life, the work of breathing shares in this elaboration of life's duties. From a stage, represented by the anemones and their neighbours, where no special breathing organs are developed and where this function appears to be performed by the general tissues of the body, we can advance to animals in which gills appear. From these organs, characteristic of water-living animals, we advance to the lungs of higher forms; and we may likewise find, midway between gills and lungs, and as representing forms of breathing-organs suited to advancing development, such a breathing apparatus as insects possess in the form of their *air-tubes*, or as spiders and scorpions possess in the shape of their *lung-sacs*.

Before we can glance with advantage, even in the most cursory fashion, at the various types of breathing-organs found in the animal world, it is necessary to ask what breathing itself means and implies. To answer this query, we may shortly reflect that breathing may soon be discovered to be in reality a duplex process. As such, it involves two important actions. One of these is *nutritive* in character and contributes to the support of the animal body. This process consists in taking into the animal body from the atmosphere directly, or from the water in which it has become mechanically suspended, a certain quantity of air. Now, as atmospheric air consists of a mixture of two gases, *oxygen* and *nitrogen*—in the proportion of about twenty-one parts of the former to seventy-nine of the latter in 100 of air—it is evident that these two gases must be inhaled by every animal that "breathes," and must be absorbed by every animal that, destitute of defined breathing-organs, yet "respires." The comparative physiologist will further inform us that for the animal—man or lower form—the oxygen is the necessary and vital gas. The nitrogen seems to be absolutely inert, and to possess no action on the animal tissues. It is believed to serve merely as a diluent to the oxygen and nothing more. Oxygen is therefore the paramount gas, so far as animal "breathing" is concerned, and in this light, it was well named of old "vital air."

Now, oxygen taken into the animal system through its breathing-organs, serves not a few important ends. It is carried to the tissues, of course, by the blood. The function of breathing-organs, in one sense, is to enable oxygen to pass

into the blood. Circulating through the animal frame, oxygen, uniting with certain materials of that frame, produces heat; whilst it subserves other functions as well. Animal life in certain low quarters may be capable of being carried on in an imperfectly oxygenated atmosphere; but, speaking generally, the gas in question may be regarded as absolutely necessary for the maintenance of animal existence at large. Deprivation of oxygen means, in other words, the death of the animal.

But besides this important use, which may be esteemed to be "nutritive" in character, in that it tends to the repair and maintenance of life's actions, breathing has yet another and different aspect. If the animal inhales oxygen, it exhales, or gives out from its breathing-organs, matter of a different nature. Suppose we try to note the difference between the air inspired and that expired from the lungs of a higher animal: we shall firstly discover that the air which is expired is *much warmer* than the outside atmosphere, and that, in fact, it resembles the blood in its temperature. Further, we shall find that, whatever the moisture of the outer air, a large quantity of moisture—provable by analysis to be *water*—is likewise given out from the lungs. The phenomenon of the moisture which condenses on the windows of a close railway carriage, as the result of its occupancy by human beings and of its imperfect ventilation, is a familiar illustration of the fact that the higher animal exhales watery vapour from its lungs. If next we breathe into pure and clear *lime-water*, we shall discover that the longer we breathe, the milkier does the water become, until at length there settles down into the bottom of the vessel a white powder. This powder, the chemist informs us, is *carbonate of lime*, or, in plain language, *chalk*. It has been formed through a gas called *carbonic acid* (CO_2) coming in contact and uniting with the *lime* of the water, and thus forming a new compound, the *chalk*, or *carbonate of lime*. This *carbonic acid* gas, which we have thus proved to come from our lungs, has further been transferred to the air from the blood. That is to say, as the oxygen we breathe in, goes *into* the blood, the carbonic acid we breathe out, comes *from* the blood.

Most persons know that this carbonic acid gas is noxious and hurtful to animal life. When breathed in sufficient quantity and for a sufficient time by men or other animals, it produces firstly stupor, then insensibility, and finally causes death by suffocation—as in the Black Hole of Calcutta itself. It is this gas which causes headaches in ill-ventilated rooms, and it is chiefly carbonic acid we try to get rid of by ventilation. As all animals "excrete," or give out, this gas from their breathing-organs, we may next inquire into the nature of this product. How carbonic acid gas is formed in the tissues of the animal through the union of oxygen (O) and carbon (C) to form the compound which the chemist writes CO_2, need not be detailed in the present instance. Suffice it to say that this carbonic acid gas makes its appearance in the animal body in the most natural of fashions. It is formed by a chemical process, the nature of which we perfectly understand; and it represents a product formed in a natural manner, and representing, as was long ago remarked, the ashes of the bodily fire. In this light we are prepared to see in carbonic acid gas so much *waste matter*, arising from the wear and tear of the animal body. It is matter, however, which, like other waste products, will cause disease and death if allowed to accumulate within the body. Hence the function of breathing appears before us in a new light, namely, as a means for getting rid of waste products—of those substances which seem inseparable from the wear and tear of life, and from the act of living and being.

As a matter of fact, in addition to the carbonic acid gas, heat, and water, given out by the breathing-organs of higher animals, there are small quantities of *ammonia*, *organic matter*, and *urea*, to be included in the list of waste substances. But if what has been just detailed has been clearly followed, it will now be apparent that when any animal "breathes" it takes in *oxygen* for the maintenance of its tissues and the production of heat, whilst it gives off *carbonic acid gas* and other products, as the waste matters of its economy. And it may be lastly remarked that breathing-organs are not the only means whereby the work of *excretion* (*i.e.*, the getting rid of waste matters) is effected. The *skin* and *kidneys* of animals are organs which, with the lungs, form a kind of natural trio engaged in the work of excretion. The two latter organs, in fact, excrete much the same kinds of waste matter as the lungs, but in different proportions: a fact proved by the circumstance that when the lungs are incapacitated by disease, the skin and kidneys may, to a certain extent, relieve the lungs of a share of their work. This fact—that of the mutual relations of lungs, skin, and kidneys—is of immense service in the

practice of the physician, in his treatment and relief of many diseases.

A survey of the chief modifications which breathing-organs may undergo in the animal world may follow the description of the general physiology of the process itself. As already remarked, breathing, like digestion, must be performed in the lower animalcules by the general protoplasm of the body. It is easy to conceive that oxygen should be absorbed and carbonic acid excreted by a medium which, as in an *Amœba* for instance, is exposed on all sides to the water. Nor is there much elaboration of matters in such an animal as a sea-anemone—high as that animal is when compared with the amœba and its neighbours. In the anemone, the sea-water laden with oxygen is received by the mouth, passes into the general cavity of the animal's body, and gives up its oxygen directly to the tissues, without the intervention of any distinct or specialised breathing-apparatus. So also in such an organism as a sponge. There we find the walls of the canals to be lined by living masses of protoplasm. These animal units must therefore claim and receive their oxygen from the continual streams of water which are ever pouring into the sponge-organism by the "pores," or smaller apertures, and which are as continually being expelled by the "oscula," or larger apertures.

In the sea-urchins, star-fishes, and like animals, distinct breathing-organs are not developed to any

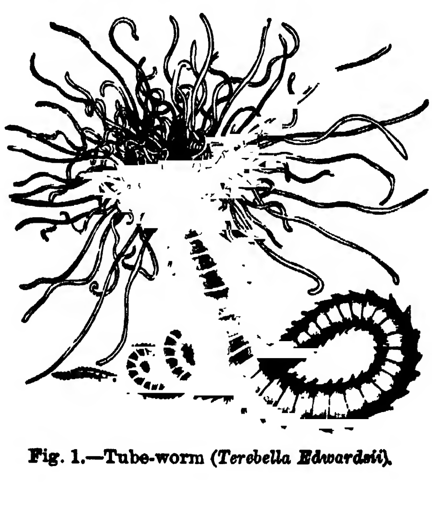

Fig. 1.—Tube-worm (*Terebella Edwardsii*).

great extent. We find that, as in the sea-anemone, there appears to be provision for the direct contact of the oxygen-laden water with the tissues. Here and there organs which have been named "branchiæ," or gills, are also developed; and a sea-cucumber (*Holothuria*) has certainly a set of plume-like tentacles around the mouth, which may possibly serve as organs of respiration.

Amongst the worms, we find examples of breathing-organs in the beautiful plume-like gills which the tube-worms (Fig. 1), met with on all our coasts, possess, attached to their head extremities. No more interesting object for microscopical examination can be procured than one of these gills. In other sea-worms and sea-leeches (Fig. 2), gills are borne on the sides of the joints that form the body.

Fig. 2.—Marine Leech (*Branchiobdella*), showing outside gills.

But as we leave the worms, and pass to the higher classes of the Annulose or "jointed" animals, new types of breathing-organs are seen. The "gills" of the lobster have already been described.* Suffice it now to say that each gill is like a bottle-brush. A whole array of these gills is contained in each side of the lobster's "chest." Water is admitted to the gill-chamber at the bases of the legs, flows over the gills, and is finally "baled" out in front by a special scoop, to make way for a fresh inflow from behind and below. From the water thus flowing over the gills, the necessary oxygen is obtained, and the effete matters are excreted into and passed from the body along with the water that is baled out of the gill-chamber.

In the insect, as a near type of the lobster, the breathing organs consist of *tracheæ*, or air-tubes; each consisting of a double membrane, inside which a horny spiral fibre is coiled, to keep the tube elastic and patent, and so to accommodate it to the movements of the animal's body. These tubes (Fig. 3) branch everywhere through the body of the insect. Air is admitted to them by apertures called *spiracles* (Fig. 4), situated on the sides of the body. Thus the insect may be said to breathe in every

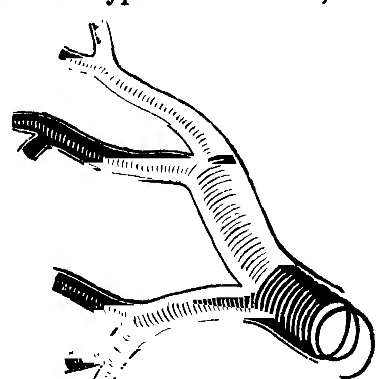

Fig. 3.—*Tracheæ*, or Air-tubes of Insect, showing spiral fibres.

* "Science for All," Vol. II., p. 40.

part, and its body is thus also rendered light for flying. Spiders and scorpions, in addition to these tubes, possess what are called *pulmonary-sacs*, or *lung-sacs*. Each of these latter organs consists of a sac or bag-like cavity, opening on the surface of the body by a distinct aperture, and containing a large number of leaf-like structures, or *lamellæ*, closely packed together like the leaves of a book. Over these lamellæ the blood-vessels ramify, and the blood in them is thus exposed to a considerable surface from which oxygen can be received.

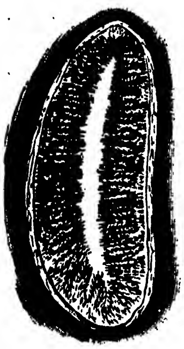

Fig. 4.—Spiracle of Water-beetle (*Dyticus marginalis*).

In the Molluscs, "gills" or *branchiæ* come prominently to the front as breathing-organs. Such are the breathing-organs of the cuttle-fishes, already described in these pages, and which receive and eject the oxygen-laden water with movements of body as regular as those whereby our own chests rise and fall. So also whelks, limpets, mussels, and the Molluscan hosts at large, breathe by gills. Only in the snails and other land-molluscs do we find a different type of breathing-organ. In these land-living forms there exists a "lung-sac," which is simply a cavity whose walls are composed of a network of blood-vessels. Into and from this cavity, the air is pumped by the forcible contraction of its muscular walls.

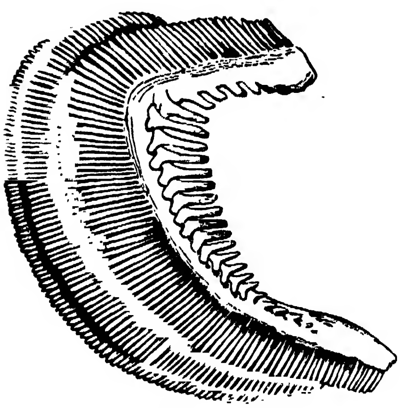

Fig. 5.—Gills of Fish.

Ascending to the backboned animals, we first enter the class of fishes. Here "gills" reign paramount as the breathing-organs. Whoever has had the curiosity to examine the gills of an ordinary fish—haddock, herring, cod, or salmon—by lifting up the gill-cover behind the head, knows that the "gills" (Fig. 5) are comb-like in form, each consisting of a number of delicate filaments like the teeth of a comb, borne on an arch—the so-called "gill-arch." Each of these filaments is a dense network of blood-vessels. The blood which is continually being sent into them by the heart is exposed to the action of the oxygen contained in the water admitted to the gill-chambers. The blood likewise gives out its carbonic acid to the water, which, taken into the mouth of the fish, circulates over the gills (lodged in gill-chambers in the sides of the mouth) and passes out behind the gill-cover. Whilst this is the common type of gill in fishes, it should be remembered that in the lampreys, and also in sharks, dog-fishes, rays, and the like, the gills are in the form of pouches, opening by slits or holes in the sides of the neck. But in every type of gill, provision is made for the circulation of water over the surface of the organ, and for the discharge of the effete water containing the waste matters.

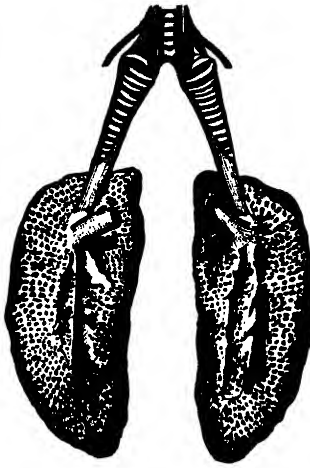

Fig. 6.—Lungs of Bird.

In the frogs and their neighbours, which begin life with gills and end life with lungs, we meet with links which connect the lower water-breathers to the air-breathers proper. In reptiles and birds, we meet with lungs alone; but the lungs of birds (Fig. 6) differ from the lungs of other animals in that they possess apertures on their surface through which so much of the air inhaled in breathing passes outwards to the body and even to the interior of the bones (p. 161). In this way, the body of the bird, like that of the insect, is rendered light for flying. No quadruped has lungs of this description. In the latter class the lungs are confined to the *thorax*, or "chest," which in its turn is completely shut off from the abdomen by a great broad muscle—the *midriff*, or *diaphragm*. It is this muscle which forms the chief agent in expanding the chest in the act of *inspiration*, or "breathing in."

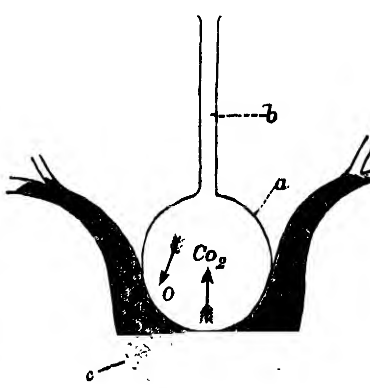

Fig. 7.—Diagram of Breathing-organ.

Having surveyed the chief modifications which the breathing-organs may be said to present, it remains for us to glance at the general type which such organs present to view. Any breathing-organ, whatever its form or nature, may be analysed out ultimately to present us with—firstly, a thin membrane (Fig. 7, *a*); having, secondly, an outlet (*b*) to the surface of the body on one side; and, thirdly, a network of blood-vessels (*c*) on the other side. These three conditions are illustrated in all breathing-organs. They are seen equally in the lung of man and in the gill of a fish or mussel. If we regard the breathing-organ as a market-place or exchange, we can readily see how, in virtue of the "law of diffusion of gases," one gas (the oxygen, O) passes inwards from air (or water) to the blood, whilst another gas (carbonic acid, CO_2) of different density, along with other waste matters, passes outwards to the external world. In some such simple idea of a membrane, with air on one side and blood on the other, we find the essentials of a breathing-organ.

Last of all, it is important and interesting to observe that we may as legitimately speak of the "breathing" of plants, as of the respiration of animals. Many plants (*e.g.* Fungi) destitute of green colour, habitually inhale oxygen and exhale carbonic acid, like animals. Green plants, on the other hand, by day absorb carbonic acid and give off oxygen (Vol. I., p. 21); but as the carbon of the carbonic acid is used as food, it is evident that this taking in of carbonic acid is a work of feeding or nutrition, and not of breathing or pure respiration alone. When the shades of evening deepen into the twilight, and when night descends upon the earth, then every green plant reverses the order of its operations by day. Then every leaf begins really to "breathe," and to inhale oxygen, whilst it gives off carbonic acid. Thus the affinity of plants and animals is seen anew in the wonderful difference to the vital processes of the former which the absence of light entails. The old difference between animals and plants, founded on the idea that the former inhaled oxygen and that the latter invariably inhaled carbonic acid, is seen after all, as an eminent naturalist put it, to be a distinction which really vanishes with the daylight. In darkness, green plants, like their colourless neighbours, respire as do the animals around them.

A COAL-FIELD.

By Frederic Drew,

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In concluding the account of what underlies London down to a depth of 1,000 feet (p. 234), it was hinted that there might be found at a greater depth still deposits of that mineral on which we so much depend for our comfort of warmth and light. At the outset I may say that coal *has not* been found beneath London, but *that* has been found which has led many who are well qualified to judge to firmly believe that coal *will* be found, either beneath London or not many miles off. This is not a mere guess, but an inference founded on a knowledge of how coal occurs, *i.e.*, of its actual position in various parts of our island and of the Continent, and of why it so lies.

It is now my object to put before the reader the facts, and to explain the inferences, which have led geologists to the belief just stated; in other words, to enable him to follow the course of the reasoning employed, to judge for himself of the strength of its foundations, and of the probability of its standing the test of experience.

For this object it is necessary that we should see the way in which coal occurs in some part where the ground has been well explored by miners and mapped by geologists; we should learn how to judge where a coal-field begins and ends; and whether it ends in such a way as to shut out all hope of the mineral being got from greater depths, or whether deeper and further explorations might extend the coal-field area.

I have chosen, to illustrate the method of answering these questions, what is often called the "Chesterfield Coal-field," that great and busy tract, denoted on geological maps by a long spread of dark grey, which extends from the neighbourhood of Derby and Nottingham on the south, through Sheffield and Chesterfield, to Bradford and Leeds on the north—a tract about sixty-five miles long, and on the average twelve miles wide. The structure of this coal-field has been well proved by the collieries that thickly stud the district, and it has been laid down by the Government surveyors in

their maps and sections, so that the knowledge gained by these under-ground and above-ground explorers is made accessible to all. The map and sec-

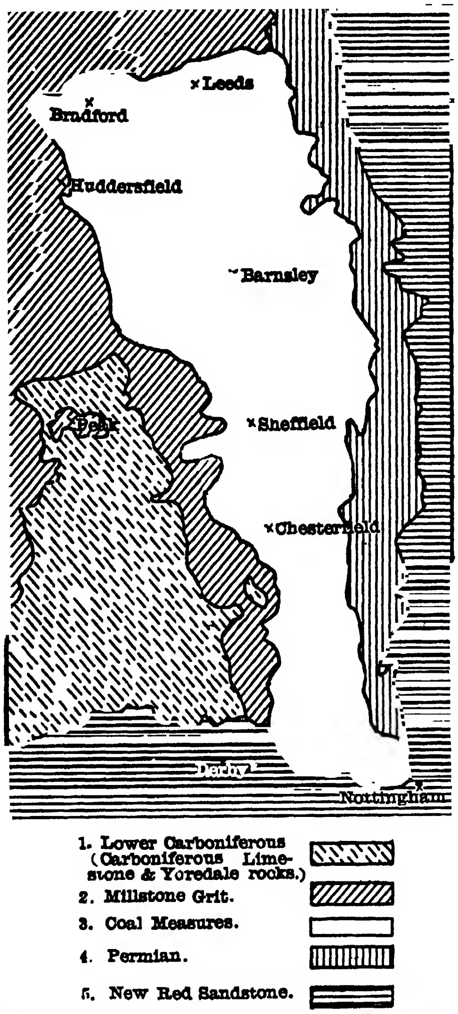

Fig. 1.—Geological Map of the Chesterfield Coal-field. (Scale, 1 inch to 20 miles.)

tion here given (Figs. 1, 2), though very sketchy as compared with the careful, detailed, and large-scale publications of the Survey, will, I believe, suffice to make clear the great general facts which it is important that we should know. They depict the area of the coal-field proper, and of tracts around it, as occupied by five sets of strata, which will be enumerated.

Since the above-mentioned strata are really the materials of which this part of the country is composed, we must consider them minutely, and look at the exact character of each. The lowest strata of which we here have cognisance, called "Lower Carboniferous," consist chiefly of thick layers of limestone, blue and grey in colour, containing, and in fact made up of, marine fossils in great variety, of which the most plentiful seem to have been crinoids or stone-lilies, and corals, though shells of the Class *Brachiopoda* also are very numerous. Details of these animals have been given already (p. 37). We have, in fact, in some places a coral reef of those times; in some places a reef, so to say, made up of stone-lilies, while on either grew numerous other kinds that contributed by their shells to amass the calcareous matter now making part of our Derbyshire Hills. These limestone strata, extending widely in every direction, have a thickness of 1,500 feet or more. Resting upon them (but still *Lower Carboniferous*) are strata of shale, with some bands of limestone, which are called "Yoredale Rocks;" these are about 500 feet in thickness. These two sets undoubtedly underlie the whole of the area we are considering, though they reach the surface in the south-western portion of it only. The rocks marked 2 in map and section consist of about 1,000 feet in thickness of thick-bedded, and in some cases hard, sandstones, to which the name "Millstone Grit" is given. They crop out all along the west of the coal-field, making the beginning of the high ground that there bounds it. An outlier, or separated portion, of the Millstone Grit, makes the summit of the "Peak" Hill, around which Yoredale rocks occupy the surface. On the north of the coal-field also Millstone Grit makes the ground—the high ground—that extends on both sides of Wharfdale, and beyond. Beneath the whole of the coal-field, as the section shows

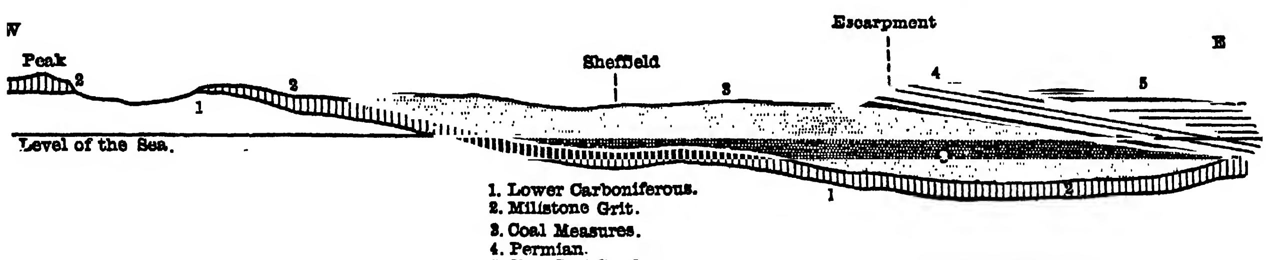

Fig. 2.—Section of Chesterfield Coal-field from W. to E., from the Peak of Derbyshire, through Sheffield and beyond.

along one line, lie these thousand-feet thick beds, *upon* the Lower Carboniferous. We now come to No. 3, which is the set of beds from which coal is got, and which go by the name of "Coal Measures." They have a thickness of 3,000 feet or thereabouts; they are beds of clay, shale (or flaky clay), and sandstone, with occasional beds of coal, some details about which will be given further on.

These sets of strata, Nos. 1, 2, and 3, belong to one great series called the "Carboniferous," and are all *conformable* one to another; that is to say, the layers of which they were composed were formed regularly one upon another, so that the top surface of each new layer was parallel, or nearly so, to the top surface of the preceding one. The exception which requires me to say "parallel or nearly so," is that one layer, as of limestone, may thin out even to nothing, in its horizontal extension; but this thinning out is not sudden. Also there has been no tilting, and no upheaval above the sea-level, of the lower layers, and no removal of any of them before the upper were deposited. All this is expressed in the language of geologists by saying that there is "conformity" through this series of Carboniferous deposits.

The next series of beds, called Permian (No. 4), are a few hundred feet in thickness of red clay and sandstone, with a bed of Magnesian limestone, or Dolomite.* These lie *unconformably* upon the beds already enumerated; that is to say, the whole thickness of the older beds had been raised up by subterranean forces, tilted and otherwise disturbed, and portions of the mass thus raised up to and above the sea-level had been worn away before the time arrived during which the Permian beds were deposited; afterwards these latter were laid down on a new denuded surface of the Carboniferous rocks—upon, in fact, the denuded edges of their strata. All this is expressed by saying that there is "unconformity" between the Carboniferous and the Permian beds.

It follows that the Permian may be found resting on any portion (higher or lower in the series) of the Carboniferous beds, as is indeed expressed on the right-hand portion of our section; for at different spots different portions of the lower set of beds were exposed by the denudation, and afterwards covered up by the Permian.

* Magnesian limestone, or Dolomite, is a mixture of carbonate of lime and carbonate of magnesia. In some parts it is a good close building stone, as some old buildings—notably York Minster, the Chapel of King's College, Cambridge, and Eton College Chapel—stand to testify.

The highest beds that are met with are the *Trias*, called also the New Red sandstone. These are red sandstones, with much false-bedding, and conglomerates. They rest conformably on the Permian, as the latter do on the Carboniferous rocks; or else they themselves rest unconformably on the Carboniferous rocks. The former case occurs to the east of the coal-field; the latter to the south, as the map will show.

This being the whole series of beds, it now behoves us to look more particularly at the Coal Measures, which, as before said, are made up of some 3,000 feet of strata, among which the coal is found. The beds of coal are of various thicknesses, from a few inches up to five or six feet. They are separated from one another (vertically) by strata, sometimes fifty feet, sometimes one or two hundred feet in thickness; but *laterally* they extend indefinitely in all directions, until at last the stratum ends at its *outcrop*, where its further portion has been eroded and removed, so that all traces of it are gone. A coal-pit, then, commonly sinks through hundreds of feet—maybe a couple of thousand feet—of sandstone, clay, and shale, penetrating at various levels various beds of coal. Of these many may be of such small thickness that the produce of them would not repay the expense of working. It happens that at the top of the series of Coal Measures there are 700 feet of such unproductive strata, with several thin coals unworked; and at the bottom, again, about 800 feet of flagstones—such stones as flake into convenient thicknesses, and are used for paving—of shale and clay, and a kind of sandstone called "gannister," with some thin beds of coal. It is the Middle Coal measures, then, that are the productive ones. We may reckon a *total* thickness of coal (all the coal-beds, thin and thick, being added together) of sixty feet; but if, as is generally considered the fair way, we only count as productive those beds *two feet thick* or more, we should have an available thickness of some forty-five feet, divided among a dozen or fifteen beds. There are now some six or eight important seams largely worked, three, four, or five feet in thickness. One of these, called the Silkstone Seam, is of such quality as to be recognised and sought for by many a householder as far as London and beyond; others have various degrees of excellence, and some have a character that fits them less for household fires than for gas-making and steam-making.

It must not be supposed that any particular colliery shaft or pit would necessarily begin at the

top of the series. It depends on what part of the coal-field it may be situated in. Looking at our section, it will be seen that close by the edge of the hill of Permian rocks there will be a greater thickness of coal measures (including a greater number of beds of coal) than would be found if a pit were made west of Sheffield; while quite along the western edge there would be found only the thin coals of the lower 700 feet, which would hardly, if at all, repay the working of them, even at the shallow depth at which they there occur. But when a shaft is sunk in the productive parts, and reaches a good bed of coal, workings starting from that shaft are carried into it nearly on a level, while, the shaft being continued lower, when a second bed of coal is reached, the working of that also would be commenced, and so in time a large and busy colliery is established; men get coal from different levels or storeys, making passages to the right and left as well as forward and backward, and bring the produce of their toil to the vertical shafts which are the general highways to the surface.

On the whole, the strata in this coal-field are very favourably situated for working. The *dip* of the beds—*i.e.*, their inclination to the horizon-plane—is never, or hardly ever, high; "faults" are not frequent (by "faults" we mean actual breaks of the strata which have occurred, interrupting the continuity of the beds, and obliging a re-arrangement of the levels of the mine whenever they are met with). The Geological Survey sections across the coal-field show but few of them; they appear to occur a quarter of a mile or half a mile apart.

At various stratum-levels *ironstone* is found; it is the clay ironstone, a mixture of carbonate of iron with clayey matter, which latter has been made into a hard mass by the cementing power of the former. The result is a layer, or else a layer of nodules, or flat roundish lumps, brown on the outside and often grey inside, yielding an ore not extremely rich, reckoned by percentage of the metal, for it contains but 30 per cent. or so of iron, but one from which the usual smelting process will extract a metal of good quality. Thus, the whole area occupied by the outcrop of the Coal Measures is one of industrial activity. A traveller to the North by the Midland Railway sees his train for fifty miles threading its way among coal-pits and blazing furnaces, and past heaps of dark shale and hard slag that tell of years of industry expended in getting coal and iron.

Both the demand for coal and iron, and the means of supplying it, have, it is well known, been increasing for years. The amount of coal raised in this one coal-field has been reckoned by millions of tons, something like twenty millions having been for some time its annual contribution to the coal supply of the world. It is an interesting inquiry, which has been followed out by well-qualified men, to calculate how long, at such a rate of expenditure, the store of coal may be expected to last. For this calculation the thickness of workable coal above given makes one element, and the area over which the various seams remain available another. The actual ending-off of the coal seams must, if possible, be ascertained, and the depth at which the deeper ones occur must be considered in reference to the practicability and cost of their exploitation. For a complete view of the coal-field, not only as actually known, but also as perhaps extending in untried directions, an examination of the country for some distance around and an understanding of *its* structure also is necessary. The map and section are here indispensable.

The lowest beds—the Lower Carboniferous, including the Carboniferous limestone—make some of the most picturesque hilly parts of Derbyshire, the ground occupied by them rising to 2,000 feet or more above the sea. The Millstone Grit also surrounds on three sides the tract of Lower Carboniferous rocks, overlying them; it spreads far to the north, beyond the range of our map. Along the line, running from near Bradford, by Huddersfield, and on by the west of Sheffield and Chesterfield to near Derby, that divides the Millstone Grit from the Coal Measures, these both dip nearly east; hence, as one goes east from this line one comes on to beds higher and higher in the coal-bearing series, and reaches in succession the various beds of coal, and so it continues even to the eastern edge of the coal-field, along which, in most places, a pit sunk would pass through a greater number of seams than it would if situated more in the middle of the coal-field. This eastern boundary is made by the Permian beds resting unconformably on the Coal Measures; the plane of junction between these two sets is, as shown in the section, not far from horizontal, hence *the coal-field really continues beneath the Permian*, giving a much larger area of productive ground than the first information, as conveyed on a map, would lead one to expect. And, indeed, the character of the surface changes along that line; the Permian strata make an escarpment, beyond which is a sloping plateau, all occupied by beds unlike those with which coal is associated. The Permian;

in their turn, pass under the New Red sandstone or Trias, which rests upon them somewhat irregularly; and on the south the New Red sandstone itself covers up all the older rocks without the intervention of the Permian.

Thus it may be said that we possess two classes of coal-fields—those where the coal, and the beds known to contain coal, crop out or are exposed at the surface, and those which are covered up by newer rocks, in all cases, I believe, unconformably, so that a deep coal-field will be found after penetrating the newer formation. When, some years ago, an alarm was raised that our store of coal was fast being consumed, and that the end of it was not far off, a Commission was appointed by Government to report on the prospects. The Commission took cognisance of these deeper coal-fields, taking the best of geological evidence and advice, and they concluded that these—for the most part untouched—fields make an important addition to our store of mineral wealth. In considering the prospects of any such coal-field, these two things must be taken into account: first, the thickness of the beds of the upper series; secondly, the lie of the beds of the lower. In the case before us, the Permian beds undoubtedly increase, though not quickly, in thickness as one goes east; in that direction, therefore, there would be a greater depth of dead or unproductive ground to sink through; still it is calculated this depth would not be prohibitive. As to the second consideration, a careful examination of the changes of the dip of the Coal Measures has led those geologists most conversant with this field to believe that its strata are, on the whole, arranged in the form of an elongated basin, as is the case with some other coal-fields, of which the boundaries are not hidden. A turning round, a change of strike, is observed at the southern end, while along the eastern side the easterly dip has lessened. It is thought that the axis of the synclinal—that is, the line along which the dip would change in direction—is not far from the margin where the Permian beds come on; beneath the Permian, the Coal Measures would rise against its base. Hence, the coal-field seen is half the basin; the other half would probably yield its riches to such enterprise as would be brought into action on any rise in the price of coal that is likely to be permanent. Some collieries have indeed already been established on the Permian beds, and one even on the New Red sandstone, which penetrated over 300 feet of these later strata before any of the Coal Measures were reached. Sir A. Ramsay estimated the hidden portion of the coal-field at 900 square miles, and Professor Hull, who has given much attention to the statistical as well as to the geological bearings of the "coal question," estimates that, besides twelve thousand millions of tons remaining in the exposed coal-field, the yield of coal-seams over two feet in thickness *from the concealed coal-field*, after deducting one-third for loss, would be over fifteen thousand millions of tons!

Thus a hunt for coal includes a search for new coal-fields. Their very obscurity gives a greater zest to the sport.

HOW A FISH SWIMS.

By Hans Gadow, M.A., Ph.D.,

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THE term "swimming," as it is used in ordinary conversation, is a very indefinite one, and it is by no means always applied to the right objects or to the proper occasion. Before we take up the subject of this paper, as to how a *fish* swims, we must, therefore, come to a clear understanding about what, in our case, is meant by swimming.

We say that a boat, or even a piece of wood swims, although the word "float" would be better employed in this case; for by floating we generally understand the mere lying of a body on the surface of the water, in opposition to its not sinking down to the bottom. This motionless floating does not apply to a fish; but there are many cases of actual progress or motion of animals in the water, concerning which we use the word "swimming" in the proper and full sense of its meaning. Thus, a a duck, a horse, or man himself swims, when supported by the water, and therefore partly floating; they make, with the help of their feet or arms, their way through this element. But there is a great difference between the swimming of such animals and that of a fish; because the former, as air-breathing creatures, have, as long as they are swimming, to fulfil two duties: first, they have to prevent themselves from being drowned, or,

in other words, to keep their heads, or at least their nostrils, above the surface of the water; secondly, they have to make their way through it, either in search of food or in order to get out of the water as soon as possible. The latter is the case with many quadrupeds, such as hares or cats, which, although not at all devoid of the power of swimming, are well known for their antipathy to water.

The fish, on the other hand, is quite in a different position: the water is its home, and moreover, as it is provided with gills, there is no fear of its drowning; thus it does not float or swim like the above-mentioned animals, *on* the water, but *in* it, surrounded on all sides by the water.

Of course, we all know that there are many invertebrate animals equally fit for living in the water; and some—as, for instance, the so-called jelly-fish and the cuttle-fish—can even make fair progress through the sea, but there is no other class of animals which combines such a high rate of speed with the graceful motions of a fish. Whether near the surface of a raging sea, or in the vast abyss of the still ocean; whether in the calmness of the inland lake, or buffeting the rush of a mountain torrent—wherever there is water, there we find fish.

We will now, therefore, glance at the structure of these wonderful creatures.

Let us take, as an example of a typical bony fish, the well-known salmon, a perch (Fig. 4), or a carp. The salmon is extremely well fitted for cutting through the water with great speed. The body in its general shape may be compared to a wedge, the thick end represented by the head, the sharp edge by the fin of the tail. A transverse section through any part of the body is of oval shape, broad near the back, narrow towards the ventral side.

This wedge shape of the body is of great advantage to a fish, which requires to swim rapidly, as, after the latter has got momentum, the currents of water produced by the onward motion of the body rush against its whole surface, and thus must press the animal forwards. The fish, therefore, resembles a wedge driven into the cleft of a piece of wood, the pressure of which upon the long sides of the wedge has the tendency to make the latter slip out in the direction of its thick end, and would certainly do so if the wedge were made slippery by some greasy substance. Another advantage of the heavier part of the body, or centre of gravity, being nearer the head than the tail will be apparent if we remember that a similarly-shaped body—for instance, the root of a carrot—when thrown into the air, will always turn its thick end forwards and the tapering point of the root backwards.

The outer surface of a fish is, as is well known, extremely slippery, the scales being directed backwards and closely pressed to the body. There is nothing that could produce any resistance against onward or head-forward motion.

The tail ends in a vertical fin, which is supported by numerous fine and elastic rays of bony matter. It is furnished with very powerful muscles, which are arranged along the sides of this organ, and can bend it forcibly to the right or left, while the up-and-down motion of the tail is very limited.

The other fins are divided into two kinds—the unpaired or vertical fins; and the paired, lateral, or horizontal fins. All the fins are supported, like the caudal fin, by bony rays, and can be erected or spread out, and be closed or laid down, in a fan-like fashion.

Of vertical fins we have, besides the tail fin, the dorsal fin; and on the ventral side, in front of the tail, a generally short anal fin.

The lateral fins are one pair just behind the head, which, as a rule, are the largest and broadest—the pectoral fins, equivalent to our arms; and one smaller pair, the ventral fins, which in the salmon or carp are situated near the middle of the trunk on the ventral side.

These two pairs of fins are the four limbs of the fish, and have muscles attached to their roots which enable them to be spread out or closed, and to be moved obliquely, up and down, forwards and backwards.

This is the typical arrangement of fins, but it must be borne in mind that, if we take the whole class of fishes, the fins are subject to as great variations in form and size as the animals themselves. Any of the above-mentioned fins may be altogether absent, or, as is the case with the pectorals in the flying-fish, may attain an extraordinary development. The rhomboid shape of a ray is due to the enlargement of the pectoral fins. The ventral fins may be removed from their backward position, and be situated just behind or even in front of the pectorals, on the throat, as in the gurnards. The dorsal fin is either very long or short, high or low, or it is split into two or three, as in the codfish. In the eel the dorsal and anal fins are very long, and are united with the caudal fin, forming a vertical fringe round the greater part of the body.

The centre of gravity of a fish is situated above

the centre of its body; its equilibrium therefore is unstable, and the animal has a tendency to turn belly upwards as when dead; how this tendency is neutralised we shall see presently.

Now, the explanation of the progression of a fish might seem obvious enough; because one might think that the four lateral fins are used like oars, by paddling the body of the fish forwards, and that the caudal fin and tail, like a rudder, are directing its course.

But this is by no means the case, and a thoroughly satisfactory explanation of how a fish swims has not yet been discovered, as in the various theories hitherto started there still remain some doubtful and puzzling points.

The progress of a fish through the water is not due to its fins, but the principal organ of motion is the powerful tail, which, as we can observe in any fish kept in a vase, makes alternately strokes to the right and to the left side.

If A, *c*, B (Fig. 2) be a line going through the longitudinal axis of a fish, with its centre of gravity in *c*, the tail-fin, when at rest, will be at the point *a*. If the fish suddenly lashes out with its tail to the right from *a* to *e*, the pressure caused upon the water by this lash is equally felt by the tail, and is transplanted to the centre of gravity, *c*, with the effect of turning the fore part of the fish to the right, just in the same way as a rudder, when turned to the right, brings the bow of the boat round to the same side.

Fig. 1.—The Common Pike (*Esox lucius*).

If the fish strike back from *e* to *a*, the motion of the fore part will be reversed to the left, and, at the same time, will be urged obliquely forwards in the direction of *c h*. If the same lash of the tail be repeated on the left side, the head will be pushed in the direction of *c h*. Both these strokes of the tail, from *d* to *a* and from *e* to *a*, according to the parallelogram of forces, will send the fish forwards in the diagonal of the parallelogram *c*, *h*, B, *i*; this is in the direction of the longitudinal axis of the fish.

As both the strokes cannot be delivered at the same moment, but first the right and then the left one, or *vice versâ*, of course the fish does not travel in a straight line; but, now being pushed somewhat to the right (i) and then to the left side (h), describes a wave-like track. This can easily be noticed if we watch a fish when swimming leisurely.

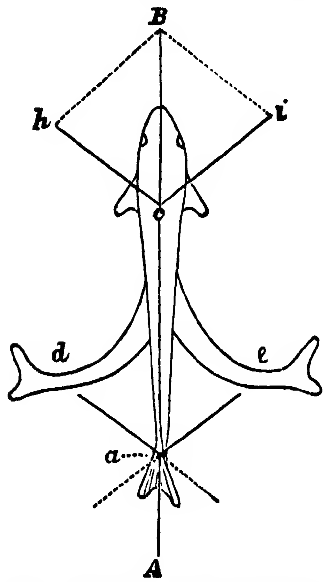

Fig. 2.—Diagram explaining the Action of a Fish's Tail in Swimming.
A B, longitudinal axis of the fish; c, the centre of gravity.

According to this theory, which was first brought forward by the great Italian mathematician, Borelli, the fish, by the action of its tail, proceeds in precisely the same way as a boat is sent through the water by a single oar passed over its stern and handled obliquely alternately to the right and left side, in a manner which we know as "sculling."

There are, however, several difficulties in this theory. The tail, while being moved from a to e (non-effective, or back stroke, as this is called by the authors), becomes curved, with the concave or biting side, e, directed forwards; while during the forward, or effective stroke, from e to a, the convex surface, and therefore the more resisting one, presses against the water. The motion of the tail from a to e, of course, retards the progress of the fish, just as frequent use of the rudder lessens the speed of the vessel.

Now, if we suppose the force resulting from the flexion of the tail equal that of its extension, there would be no progress of the fish whatever, as both the back and the forward motions neutralise each other; moreover, if the flexion of the tail be more effective than the extension—and this would certainly be the case if both the strokes were made with the same force, as the back stroke has the advantage of the biting surface—there would be a retrograde motion, and the fish would go backwards from c to A. But as the fish swims forwards by the aid of its tail, either the theory of the sculling motion of the tail must be incorrect, or there must be some further explanation of the discrepancy between theory and practice.

There are, indeed, at least four circumstances which would cause the extension stroke to have a surplus of power, and would explain the difficulty.

Firstly, the tail while making the outward stroke from a to e may move less rapidly than when lashing from e to a or from d to a.

Secondly, the fin of the tail during the outward-stroke is either folded or less expanded, while during the extension, or inward stroke, the caudal fin is kept rigidly extended. Moreover, the muscles of the tail incline its broad plane and that of the terminal fin to the direction of its sideward motion, while as it passes towards a they present their whole plane perpendicularly to the line A B. This inclination, combined with a partial folding and expanding of the fin, would enable the tail to strike more powerfully in the direction towards a than from the line of progression.

Again, the fish, when once in motion, causes a current behind it in the direction from A to B; this current offers comparatively but little resistance to the tail during its outward-stroke, whilst the reverse stroke towards a meets with a much greater resistance, and thus makes this stroke more effective than the other.

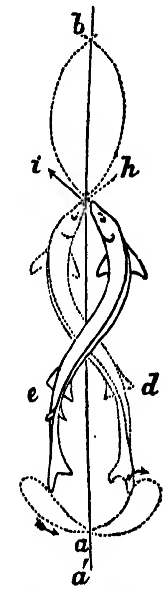

Fig. 3. — Diagram of the Swimming of the Sturgeon, showing the double curve into which the body of the Fish is thrown. The dotted line with the two arrows shows the way and the direction described by the tip of the tail. (*Adapted from Pettigrew.*)

The above considerations will give a sufficient explanation of the *slow* onward progression of a typical fish, like a salmon, perch, or carp, the slow motions of the tail of which we can easily watch.

But there are other fishes to which this theory is not applicable. This was first pointed out by Professor Pettigrew. He observed that in the sturgeon, the movements of which are very slow and deliberate, the whole body in swimming is always thrown into two curves: one — the cephalic curve, as he terms it—made by the anterior half of the body; the other, a caudal one, by the tail. These two curves are opposite to each other, the convex surface of the one looking to the right, that of the other to the left, as is seen in Fig. 3. This enables the sturgeon, during the flexion of the tail from the line a b towards e, to present always the convex, or less resisting, side to the water, whilst during the extension of that organ its biting, or

concave, surface is acting. During the extension of the tail, when it is travelling towards the middle line, *a b*, the cephalic curve balances, so to speak, the caudal one; and the head travels over the line *a b* towards *i*. When the tail is extended, it is immediately thrown over to the left side towards *d*, and the cephalic curve to the right; the fish is then in the position indicated by the dotted lines.

Thus the tail may move from side to side with the same rapidity during both strokes, and as the animal always strikes the water with the biting, or concave, surface during the extension stroke (which, as we have explained before, produces the forward motion) and with the convex side during the flexion stroke, the former has constantly an enormous advantage over the latter—the resistant force of a concave body to that of a convex one under the same conditions being in the ratio of two to one.

Another advantage of this kind of swimming is that, although the tail is moved rapidly from right to left, the tip always remains nearly in the line of progress, *a b*, and so greatly assists in steadying the course of the animal.

Again, during the flexion of the tail, the caudal fin is not kept in a plane, but is curved in two directions—let us say, the upper end to the right, and the lower one to the left—and the tail itself with this curved fin is slightly inclined to the side of its flexion.

When near the middle line the tail, of course, is straight, and so is the plane of its fin, kept perpendicularly in the same line. After the tail has passed the latter, all the positions are reversed. Now, it is clear that as by the flexion of the tail the fin is drawn forwards from a^1 towards a (Fig. 3), the fin is caused to press with oblique planes against the water and act like a ship's screw. It is, however, far better than such an artificial screw, because when passing the line *a b* the position of its blades is immediately reversed, and as long as they are in the middle line they are kept straight, and do not offer any resistance to the water; whilst the screw of a ship, without exception, is under the great disadvantage that a considerable portion of the force exerted by its blades upon the water is directed backwards, and that the screw, if revolved beyond a given speed, ceases altogether to be effective.

In a similar way as is described in the sturgeon all those fishes move which, like the eel, are of a greatly elongated form, and which, as a rule, have their tail surrounded by a very long but low fin. Such fishes bend their bodies in several curves, but always in an even number, so as to compensate or to balance each other.

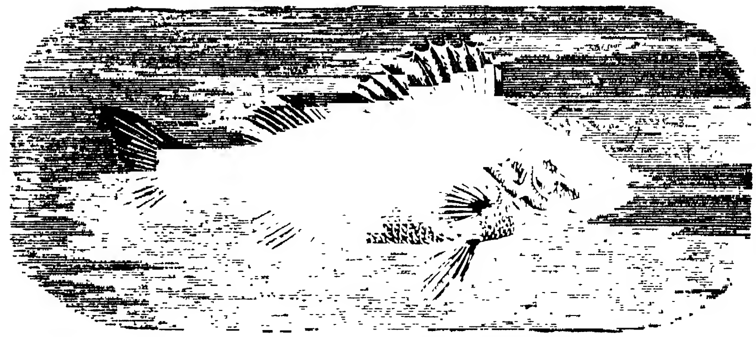

Fig. 4.—The River Perch (*Perca fluviatilis*).

Again, not only the long and slender fishes, but also the shorter and stoutly-built ones, like our carp and perch, if they want to swim quickly, make undulating motions with their bodies. The only difference is that the fore part of their body can scarcely undergo any visible bending. If we watch such a fish when in quick progression, we see the hinder half of its body rapidly thrown into short undulating curves, which seem—as it appears to the looker-on—to come out of the trunk, and are directed towards the end of the tail. As these undulations are smaller towards the trunk, as the less flexible part of the fish, and greatest on the blade of the caudal fin, which, as described above, they whirl in a screw-like fashion, all the continuous pressure against the water is directed backwards. This force, being transplanted to the body of the fish, drives the latter on in the opposite direction, head-forwards.

The screw-like motion of the tail is also used amongst mammals—by the whales, and by the manatee; however, we must remember that in these animals the two blades of the tail, or the "flukes," as they are called, are not placed vertically, but lie horizontally, and, consequently, that the strokes are delivered in an up-and-downward direction. A whale, according to Beale, when undisturbed, passes tranquilly along just below the surface of the water, at about three or four miles an hour, which progress he effects by a gentle oblique motion from side to side of the flukes. When desirous of proceeding at a greater rate, the action of the tail is materially altered; instead of

being moved laterally and obliquely, it strikes the water with the broad flat surface of the flukes in a direct manner, up and downwards. As Dr. Murie first observed, the lobes of the tail, when dried, "assume opposite concave-convex curves, so as to produce a very close resemblance, both in curve and angle, to the blades of a screw-propeller;" and in the museum of the Royal College of Surgeons, in London, there are preserved the extremities of the tails of several dolphins, which, after being dried, remain in this position. This seems to prove that the whale bends the flukes into the same shape, and, therefore, that the mere act of striking up and downwards of the tail would produce a screw-like action, and drive the animal forwards in the direction of its longitudinal axis.

But this is not the only use of the tail. If the fish, when progressing through the water, keeps the tail bent to the right or to the left, with the concave side directed outwards, it will turn to the same side; and the tail therefore acts precisely like a ship's rudder. Again, many fishes, by giving a single forcible stroke to the water with their tail in a vertical direction, throw themselves out of the former. This they do for many purposes—either to catch an insect which flies over the surface, or to evade the voracious mouths of their enemies, such as sharks, pikes (Fig. 1), dolphins, and other ravenous inhabitants of the deep. The salmon is well known for the jumping power of its tail, by the help of which it is enabled to overcome the various obstacles in a river, as weirs or bars. The height of such a leap, although often greatly over-estimated, is known for certain often to amount to more than six feet.

Hitherto we have only spoken of the progression of the fish in the direction of its longitudinal axis, and many of our readers will be astonished that they have not heard even a mention of the other fins. As there exist no fishes which are absolutely without fins (for if the paired ones are greatly reduced the vertical ones are more developed, and *vice versâ*), it follows that the fins must naturally be of great service to the fish.

The main function of the fins—with the exception of a few particular cases where they are really propelling organs, as we shall see later on—is to balance the fish's body and to steady its course. It will be easily understood that the vertical dorsal and the anal fins, as they lie precisely in the longitudinal axis of the body, must find their representatives in the keel of a ship, and thus accomplish the same purpose as that mechanism.

The paired fins act in a similar manner; for, by moving slightly up and downwards, they balance the body and keep it at the same level above the bottom.

This has been proved by experiment. A fish deprived of its pectoral fins sinks down with its fore-part, and assumes an oblique position. If the pectoral and the ventral fins of one—for instance, those of the right side—are removed, the fish rolls over to the right; and if deprived of the fins altogether, it turns completely round, belly upwards, like a dead fish, in which, of course, the fins have ceased to act. If its dorsal and anal fins are cut, the course of the animal assumes a zigzag and very unsteady line.

A few down-strokes of the pectoral fins will raise

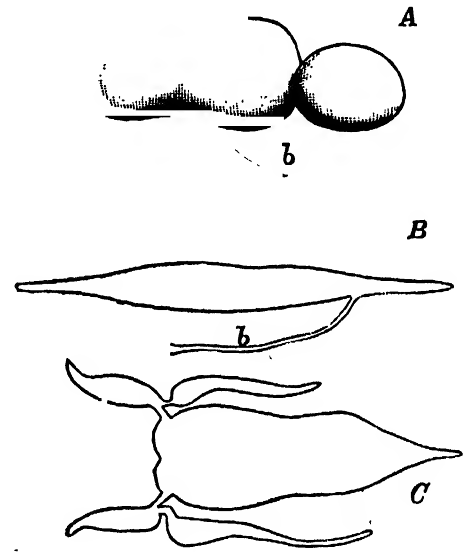

Fig. 5.—A, Air-bladder of the Common Carp (*Cyprinus carpio*). In this Fish the Air-bladder consists of two Sacs, the posterior and larger one of which opens by a Duct, *b*, into the Stomach. B, Air-bladder of the Herring (*Clupea harengus*); *b*, the Pneumatic Duct opening forwards into the Stomach. C, Air-bladder of *Corvina trispinosa*, dorsal view; the anterior part of the Air-bladder branching off into several peculiarly-shaped Sacs of smaller size.

the anterior half of the fish, and will bring it nearer to the surface; if only the right fin be used, and make a few down-strokes, the creature will turn over to the left, and will take the oblique position characteristic of a shark when about to seize its prey, as it is obliged to do owing to the position of its mouth. Again, the backward striking of the right fin, whilst the other one is compressed to the body, will wheel the fish round to the left. In fishes which, like the sharks, swim near the surface of the ocean, and which therefore have often to deal with the force of the waves, we see all the fins, including that of the tail, well developed and more strongly constructed than in other fishes which live

near the bottom of the sea, or prefer the calm fresh-water lakes.

Whilst inquiring into the action of the paired fins, we must further bear in mind that they are placed in different positions in different kinds of fishes. Thus, in the shark their planes are more or less horizontal, and consequently their strokes are generally delivered in an up-and-down direction; whilst in the carp the pectorals are more removed from the ventral side, and inserted nearer the lateral line, with their planes standing almost vertically; therefore, the strokes of such fins will be with muscles which can compress the air-bladder and diminish its size, so that the specific gravity of the fish, which is nearly like that of pure water, gets greater. The fish in this case will sink. If the air is pressed into the anterior cavity and the hinder one partly emptied, the centre of gravity is shifted backwards, and the fish will assume an oblique position, with its head rising, and *vice versâ*. In this way the presence of an air-bladder must greatly assist the fish in its motions; but it must be remarked that this hydrostatic use of the air-bladder may only have been fortuitous, and that

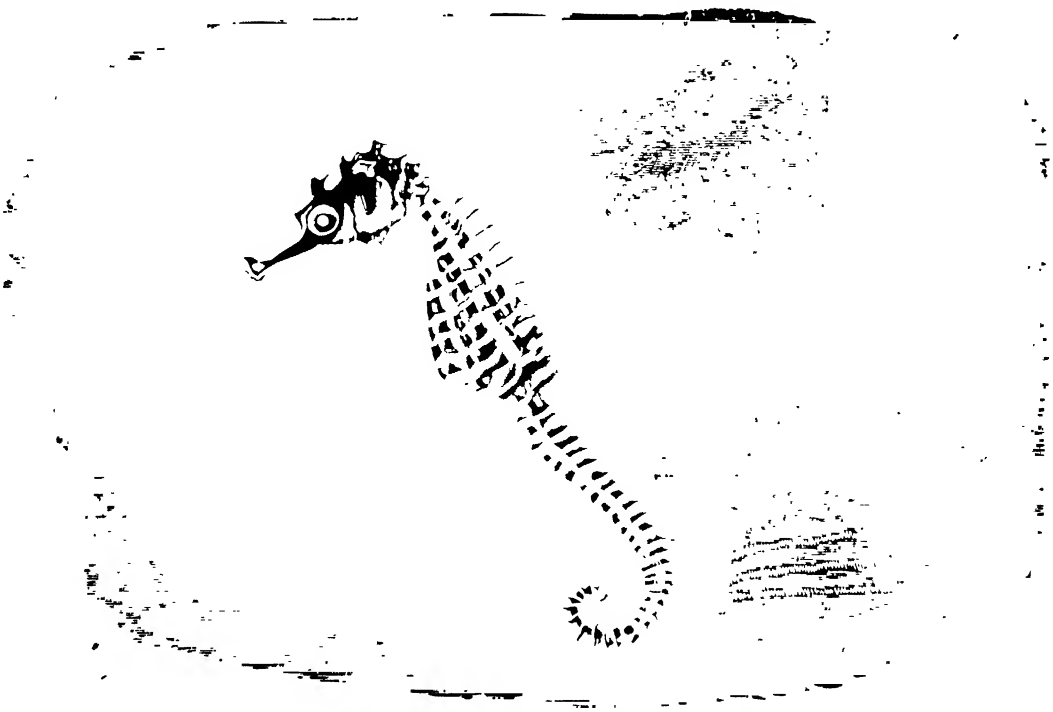

Fig. 6.—The Sea-horse (*Hippocampus brevirostris*).

delivered backwards and forwards, and can, if necessary, add to the progression by paddling like the oars of a boat.

Many fishes—as, for instance, the rays and sharks—do not possess an air-bladder (Fig. 5), which is a proof that this organ, the purpose of which has been so much contested, is not essential for swimming. In the vast majority of fishes, however, the air-bladder lies in the cavity of the body between the back-bone and the intestines, and is filled with gases of various composition. Its shape and size are subject to the greatest variations. In a numerous group of fishes the air-bladders open by a duct into the intestinal canal, and thus may be partially emptied; in others there is no aperture whatever. (Vol. I., pp. 332, 333.)

In many fishes the walls of this organ are furnished

its main purpose may be for some kind of respiratory function.

We have seen how a typical fish swims, and we have only now to remember that there exist many other fishes which move, as it seems, in quite a different way. The rays swim by flapping with their enormously-enlarged pectorals, and the tail is only little used; the flat-fish move their whole bodies in several wave-like curves up and downwards; the pipe-fish progresses by means of an undulating motion of its long dorsal fin; and the sea-horse (Fig. 6) uses the same organ in a whirling screw-like fashion. But these are more or less extreme cases of the elaboration of arrangements which, after all, are dependent upon the same general principle as those more typical cases which alone could here be treated in detail.

FIRE-DAMP AND THE SAFETY-LAMP.

By Ira Remsen,

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I side of a pool of stagnant water is not the most attractive spot that could be selected for the purpose of studying nature; but we should not have to remain there long before noticing that the surface of the water is from time to time disturbed by the rising of bubbles. If we should stir up the material at the bottom of the pool with a stick, the bubbles would rise much more rapidly. They might rest for a moment on the surface of the water, but they would then burst and there would be nothing visible left. Any one with an inquiring turn of mind would at once ask, What causes these bubbles? They look like air-bubbles, but how can air be given off from the bottom of a pool? In order to determine what the substance is which thus rises through the water and escapes, we must in some way get possession of it, and then study its properties. To accomplish this it is only necessary to bring a good-sized bottle under the surface of the water in the pool, and, after it is filled, invert it, and place a funnel in its mouth. The funnel should be tied to the bottle to prevent its falling. Now if this piece of apparatus is placed over the rising bubbles, they enter the bottle instead of escaping into the air, and, as they enter, an equal volume of water is driven out, and gradually the bottle becomes filled with the gas. If the bottom of the pool is stirred up the amount of gas which rises is increased in quantity, and the process of filling the bottle is hastened. The accompanying illustration (Fig. 1) will show clearly how the apparatus is managed.

A very slight examination is sufficient to show that the gas in the bottle is not ordinary air. If a lighted match be applied to it, it takes fire and continues to burn. If examined in the laboratory by the most refined methods of chemical analysis, it is found to consist mainly of one gas, while mixed with it are some other substances which may be regarded as impurities. The fact that it is found in stagnant pools or, in general, in marshes, has given it one of its names, *marsh gas.* It consists of two elements, hydrogen and carbon, and is hence known as a *hydro-carbon.* A very large number of these hydro-carbons are known to chemists, and a great deal of time and labour has been spent in studying them. It is now known that most of those intricate and interesting substances which are found in the organs of plants and animals may be derived from the hydro-carbons. Petroleum (p. 121) is made up of a number of different hydro-carbons. Some of these are gases at ordinary temperatures, some are light liquids which are converted into vapour by a very slight amount of heat, while others require a greater amount of heat, and so on. Now of all the hydro-carbons, marsh gas is the simplest. It is, as it were, the

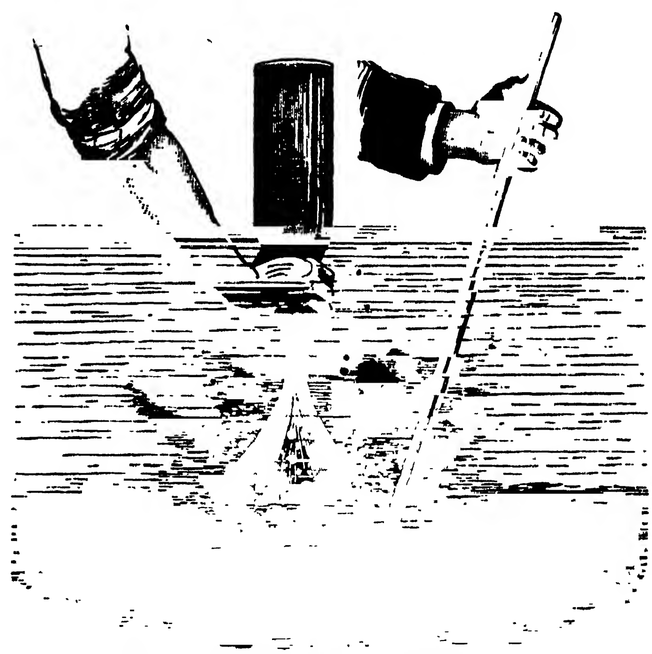

Fig. 1.—Collecting Gas from a Stagnant Pool.

mother-substance of the whole group, and, in consequence, it is of great importance in chemistry, and a *complete* account of it would involve a discussion of many of the most profound problems of the science. But let us rather keep in mind matters of more general interest to those who are not chemists, for there is enough to occupy us profitably without going into abstruse scientific questions. Let us attempt to discover why marsh gas rises from pools of stagnant water; whether it is found under other conditions in nature; how we can make it in our laboratories; and why it has attracted general attention, and, under another

name, has become the terror of the inhabitants of coal-mining regions.

In marshy pools there are always the remains of plants in the form of grass, leaves, &c., and these, as we can easily convince ourselves, are undergoing decay. They are made up mainly of carbon, hydrogen, and oxygen, and it appears probable that the marsh gas owes its formation to this process of decay, but without proof we should not be warranted in accepting this conclusion. There may be other substances in the water or under the earth which give rise to its formation. To test this, we may collect some leaves and other parts of plants, place them under pure water in clean vessels, into which no foreign matter can gain access, and then expose the mass to the action of the air and sun. Slowly the process of decay will begin, and in time we shall have an artificial stagnant pool. It will be found that this will conduct itself essentially like the pool in the marsh. The bubbles will rise, and stirring the mass at the bottom will increase the amount of gas given off. On collecting the gas and comparing it with that obtained from the marsh, the two will be found to be identical. The leaves and other materials placed in our tank will be found to have undergone change. They will be seen to be disintegrated and darkened in colour. This experiment proves that marsh gas may owe its existence to the decay of vegetable matter under water, and it is fair to conclude that this is the cause of its formation in marshes.

If the vegetable matter were left exposed to the air it would also undergo decay, but the products would not be the same. The oxygen of the air would convert all the carbon into carbonic acid, and the hydrogen into water. Under the water, however, there is not enough oxygen to effect these changes. There is, to be sure, some oxygen in the substances themselves, and this combines partly with the carbon, forming carbonic acid; but there is not nearly enough of it to convert all the carbon in this way, and that which is left combines with the hydrogen to form the hydrocarbon marsh gas. The difference between the process of decay in the air and under water, is similar to the difference between burning a piece of wood with free access of air and heating it in a closed vessel. In the former case we know the wood burns up, as we say; that is, it disappears almost completely; and if we were to examine the smoke, we should find it to consist largely of carbonic acid and water. In the latter case, after high heat has been applied to the vessel, and the change is completed, there is left a black mass, which we call charcoal, consisting mainly of carbon. Among the substances given off there is always under such circumstances a considerable quantity of marsh gas. The decomposition of the vegetable matter in the closed vessel is to be compared with the decay under water, in so far as both processes are effected without access of air.

The simple experiment with the vegetable matter in the tank of water, represents in miniature not only the changes which are going on in marshes, but mightier changes which have taken place in ages past, and which have resulted in the formation of our great coal-beds. It has been shown by geological, and botanical and chemical examinations, that these coal-beds are the remains of vast forests which were at one time submerged, and then, under peculiar conditions, underwent partial decay. Among the products formed in the first stages of the process, there would naturally be marsh gas, and it is probable that this gas would continue to be formed as long as the material undergoes change. At first this would escape for the most part, but as the mass of coal by continued change became harder and harder, and as it came to be covered by layers of earth, and these in turn became harder and harder, forming an impervious layer above the coal, the escape of the gas would be, at least, partly prevented. It would tend to collect in cavities in the coal and there remain, accumulating slowly, until by its own ever-increasing pressure it forced an opening of escape, or until man, in his advances upon nature's stores, set it free by accident.

Of course, unless marsh gas is actually met with in nature in connection with coal-beds, the above remarks would be but idle speculation, and would scarcely be worthy of attention. But if, reasoning upon a basis of well-established facts, we are led to expect the formation of a certain substance under certain conditions, and we actually find that the substance is formed under these conditions, then we may fairly conclude, until evidence to the contrary is produced, that our reasoning is correct. This is exactly the state of the case with reference to the occurrence of marsh gas. The gas is found in enormous quantities in connection with coal-beds, just as we should expect, and not a year passes that we do not hear of its escape, and the awful consequences which usually follow. But we are anticipating.

In some parts of the earth there are fissures in the ground from which a gas is constantly escaping.

On the shores of the Caspian Sea at Baku such a gas is burning, and has been burning for ages, forming the celebrated sacred fire of Baku. This place was formerly visited annually by thousands of pilgrims, and is still visited by a few Persian fire-worshippers. "Fifteen miles north-east of Baku is a fire temple; a remarkable spot, somewhat less than a mile in circumference, from the centre of which a bluish flame is seen to arise. Here are small houses, and the inhabitants, when they wish to smother the flame, cover the space enclosed with walls by a thick loam of earth. When an incision is made in the floor, the flame arises; and when it is no longer wanted for culinary or other purposes, it is again suppressed by closing the aperture. The whole country around Baku has at times the appearance of being enveloped in flames. It often appears as if fire rolled down the mountains in large masses with great velocity; and at night a bright blue light is observed to cover the whole western range of hills." Large quantities of naphtha are obtained from this region, which evidently resembles the Pennsylvania oil districts. The gas has been collected at Baku and examined, and found to be mainly marsh gas, and it is supposed that the fissures from which it escapes communicate with subterranean coal-beds, in which the gas accumulates under pressure, and then forces its way out through the earth. In the village of Fredonia, in the State of New York, the same gas also escapes, but it has never formed the sacred fire of the New World. It has long been treated prosaically, being utilised for illuminating purposes—nature, in this case, enabling the inhabitants to dispense with the expensive luxury of gas-works. Wherever there are petroleum wells this gas is present, and escapes from the cavities which are punctured for the purpose of procuring the oil, and the escape is in some cases so abundant that the material is utilised for heating and illuminating purposes.

I have thus mentioned the chief conditions under which marsh gas is found in nature, and it will be seen that these conditions are probably all of the same general nature. They are such that the decay of vegetable matter can take place without access of air, and this decay may be looked upon as the cause of the formation of the gas wherever it may be found in nature, whether rising slowly from the bottom of the stagnant pool; bursting suddenly forth from its enclosure in a coal-bed; issuing from the fissures which it has made in the earth; or accompanying the other hydro-carbons which go to make up that valuable and complicated mixture, petroleum.

As was stated above, the gas is formed when wood is heated in a vessel in such a way as to prevent the free access of air. Many other substances are formed at the same time, some of these being liquid, and others gaseous. All the gaseous portions mixed together form a very good illuminating gas, and in some places it is found to be convenient and profitable to heat wood for the express purpose of manufacturing gas. So, also, when the different varieties of coal are heated in closed retorts, they, as is well known, give off gases and liquids, and leave behind a solid. Some kinds of coal yield much more gas than others; and these are used for the purpose of manufacturing coal-gas (Vol. IV., p. 167). Coal-gas always contains a considerable quantity of marsh gas. Thus it is seen that we may either start from the vegetable matter, and by a very slow series of changes, obtain marsh gas; or we may heat it, and obtain the gas at once; or we may take one of the products of the change of vegetable matter—namely, coal—and by heating this obtain the gas.

But while all the processes mentioned lead to the formation of marsh gas, and in some cases in enormous quantities, to obtain it in pure condition, for the purpose of study, it is much more convenient to simply mix together acetate of sodium, caustic potash, and lime, and then distil. In this way we can obtain possession of any desired quantity, and in purer condition than that which we get directly from nature.

And, now, what are the properties of marsh gas? The fact that it burns has been repeatedly stated. When it burns it is converted into carbonic acid and water, and nothing else. It is not an active poison, but if it were to be breathed into the lungs for any length of time death would ensue from lack of oxygen, in much the same way as in the case of drowning. It has no odour and no taste. But one of its most striking properties is its power of forming explosive mixtures. If it be mixed with air in certain proportions, varying between six and fourteen parts of air to one of the gas, it only needs a spark to cause the entire mass of gaseous mixture to explode with violence, the violence of the explosion varying with the proportions of the constituents. A mixture of one part of the gas with eight to ten of air is the most explosive. We can, of course, easily make such a mixture in the laboratory, and, if this be brought into a vessel with a large mouth, it may be exploded without danger, by

applying a lighted taper to the gas at the open mouth. Or evidence of the force of the explosion may also be obtained by inflating a mass of soap-bubbles with the mixture and applying a light. It would require but a few such experiments to inspire us with respect for the gas. Other hydro-carbons besides marsh gas have this same power of forming explosive mixtures with air. This is particularly true of the hydro-carbons in petroleum, and the lamp explosions which we hear of altogether too frequently are due to the presence in the petroleum of certain volatile hydro-carbons, which should be removed in the process of refining. These are readily converted into gases, which, when mixed with air, give rise to the explosions.

With the facts already in our possession, we are prepared to divine the cause of colliery explosions, and for the consideration of certain matters of importance connected with them. No one need be told of the frequent occurrence of terrific explosions in coal-mines, often involving enormous loss of life and the destruction of a vast amount of property. From what has been said, the cause of these explosions must be clear. The marsh gas escaping from coal-beds is likely to be met with at any time in a coal-mine. It may be given off gradually, and in small quantity, and do no harm if good ventilation is kept up; but let new cavities be opened, or let fissures be formed, so as to permit of the escape of a large quantity of the gas, and what will be the consequence? As soon as a mixture of the proper proportions of air and the gas is formed, it only requires the momentary contact of a flame, or spark, to cause the dreaded explosion. The miners are familiar with the gas, and, from the fact that it burns, they call it *fire-damp*. In a similar way, carbonic acid, in which breathing is impossible, and which does not burn, is called by them *choke-damp*. The terrors of both of these are encountered in coal-mines, and, in fact, in the case of an explosion, both may contribute to the fatal results. When the explosion occurs, the fire-damp, or marsh gas, is converted into choke-damp, and an occupant of the mine may escape the direct effects of the explosion, only to be stifled to death by the choke-damp before he can make his escape.

As the setting free of fire-damp is necessarily connected with the opening of coal-beds, and as the miners must have light to enable them to do their work, explosions would seem to be unavoidable. Of course, we think at once of protecting the flames of the miners' lamps, but if we cut off completely the communication between the flame and the air the flame will certainly be extinguished. Here, then, is plainly an important and difficult problem for solution. We know that the fire-damp of the miner is likely to show itself wherever new openings are made in the coal-beds, that, indeed, in some mines it is constantly escaping; we know that it is very dangerous to have unprotected flames in the mines, and we know that the flames must be there, and must communicate with the air, in order that they may continue to burn. Is it possible to avert the danger? This question had frequently been asked, we may believe, before it was finally answered. In the early part of this century a number of gentlemen residing in the colliery districts of England, being fully aroused to the great dangers connected with the work of the miner, formed themselves into a committee to investigate the subject. They succeeded in engaging the services of Sir Humphry Davy, who was then at the height of his popularity, and he at once began a series of careful studies, which resulted in a satisfactory solution of the problem. He invented the "safety-lamp," which, in spite of numerous rivals and its admitted imperfections, is still in use, having undergone but slight modifications since it was perfected by him. This lamp is a very simple piece of apparatus, but, in order that we may thoroughly understand it, it will be necessary to inquire into a few principles upon which its success depends.

In the first place, then, we must bear in mind what a flame is. The lamp burns, as we say. That is, the oil with which the lamp is filled, is drawn up by the wick; it is then heated and converted into gas, and the gas burns. Now a flame, no matter where we may meet with it, no matter from what it may be formed, is always *a burning gas*. The gas may be furnished directly, as in the case of our ordinary illuminating gas; or it may be made from a liquid, as in the case of lamps; or it may be made from solids, as in candles, or in the burning of a piece of wood or coal. But in all these cases the material is converted into a gas, or a mixture of gases, before the flame appears. In order that a gas may burn, it must first be heated to a certain temperature, called its *temperature of ignition*. This is equally true of everything capable of burning. Take a piece of wood, for example. We know that this wood must be heated to a high temperature before it will burn, and then the whole piece does not burn at once. The burning begins at the heated point, and from this point heat enough is communicated to the parts immediately adjoining it to cause them to burn. These, in turn, heat up the succeeding parts, and so on, until the entire

mass is affected. We know how difficult it is to get a large piece of wood to burn sometimes. This is due to the fact that we cannot get a large enough part of it heated up to the burning temperature to communicate the requisite heat to the rest. If we cool down any burning body below its burning temperature, the burning necessarily ceases.

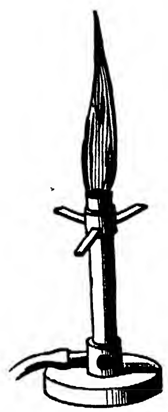

Fig. 2.—Flame in Ordinary Condition.

By means of a few simple experiments we may illustrate these facts with a flame. The flame of an alcohol lamp will answer the purpose, but a gas flame from a Bunsen burner, such as is commonly used in laboratories (Fig. 2), is better. Both these flames have the one property in common, that they do not deposit soot upon objects placed in them. Now light the gas, and bring down upon it a piece of brass or iron wire gauze. A piece four or five inches square may be held at one corner in the hand. It will not grow too hot during the experiment. Although the amount of gas which escapes from the burner is the same now as before the gauze was placed over the flame, there is no flame above the gauze. We may even press the gauze down very near to the burner without the appearance of any flame above it (Fig. 3). But if we apply a lighted match to the upper part of the gauze, a flame appears immediately, and continues to burn, the gauze now having no perceptible influence on it.

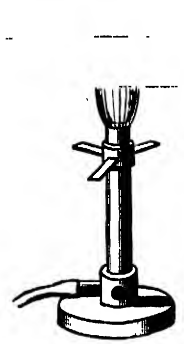

Fig 3.—Flame with Wire Gauze.

If, on the other hand, the gauze be held about two inches above the burner before the gas is lighted, a light applied above it will cause a flame to appear above, but not below it (Fig. 4), while, if the light be applied at first below the gauze, the flame will appear below, but not above it. In either case the flame may be made continuous by lighting the gas above *and* below the gauze. (Vol. I., p. 354.)

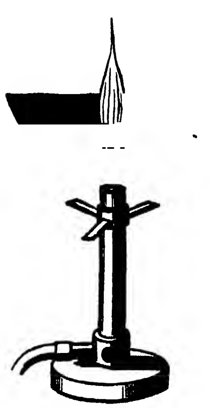

Fig. 4.—Flame above the Gauze.

Or, further, a spiral of wire may be so introduced into the flame of an alcohol lamp (Fig. 5) as to extinguish it, though the spiral plainly does not act as an ordinary extinguisher, for it cannot exclude the air. Thick copper wire is well adapted to the purpose. It should be quickly introduced.

How shall we explain these simple facts? It can be shown that they all depend upon the cooling of the gases. The wire gauze placed in the flame conducts off a certain amount of heat, and is not at first as hot as the flame, hence that portion of the gas which passes through the gauze is cooled down slightly below its temperature of ignition, and cannot burn. But if we light it, that is, heat it up to its temperature of ignition, then it furnishes the necessary heat to light those portions of gas which afterwards pass through the gauze. A similar explanation of course holds for the second case mentioned, viz., that in which the flame is first above the gauze. There is not enough heat conducted through the gauze to set fire to the lower column of gas. Similarly the alcohol flame is extinguished because it is cooled down by the spiral.

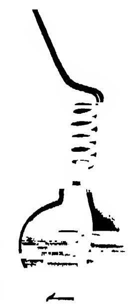

Fig. 5.—Flame extinguished by Spiral Wire.

We have thus given the commonly accepted explanations without giving any proof of their correctness. If they are correct, then it must be only necessary to heat up the gauze in the first experiments and the spiral in the last to prevent the effects described. This can easily be tested. If the gauze remain long enough in the flame to become heated up to the temperature of the flame, the latter strikes through. Or if the gauze be hot enough when brought down upon the flame, no effect is produced. So also if the copper spiral be heated before it is introduced into the alcohol flame, it does not act as an extinguisher. A great many other experiments might be described, proving the same thing.

It has been found further that metallic tubes of small calibre, as well as gauze, prevent the passage of flame. Tubes one-fifth of an inch in diameter and an inch and a half long are efficient. Or a bundle of wires placed in a larger tube, in such a way as to fill it as far as possible, forms an apparatus which has the same power. Such a tube is sometimes used for the purpose of safety in connection with explosive mixtures of gases. It being impossible for flame to pass through it, of course its attachment to a vessel containing an

explosive mixture will diminish the danger. In short, anything consisting of metal, and in which the apertures are small, will effect the cooling of gases which pass through, and if the gases are burning on one side of the apparatus, the flames are extinguished in passing through.

But what has all this to do with Davy's safety-lamp? The object of this lamp, as we know, is to prevent explosions of mixtures of fire-damp and air, and still permit the use of lights in the mines. When a flame is applied to such a mixture, there is an instantaneous burning of the mass, the burning temperature being very rapidly communicated through the mixture. The elevation of temperature which accompanies the burning causes a sudden and great expansion of the gases; and the rapid burning and expansion together constitute the explosion. Gunpowder explodes in a similar way. It requires but a spark to decompose the smallest particle of the powder, and the action is then communicated with great rapidity through the mass. When it decomposes, it is converted largely into gases, and the volume is enormously increased. In both cases the main act is that of burning or combustion, and this takes place so readily because the substance burned is intimately mixed with the substance which furnishes the oxygen necessary for the combustion. In the mixture of fire-damp and air, it is the former which burns, and the latter which furnishes the oxygen. In the gunpowder, two substances, carbon (charcoal) and sulphur, burn, while the oxygen is furnished by the saltpetre, the third constituent, which contains a large proportion of the gas.

The explosion then is a rapid combustion. But we have seen that a gas must be heated up to a certain temperature before it can burn, and, if we can prevent the mixture in the mine from becoming heated up to this temperature at any point, the explosions can be averted. The wire gauze may be brought to our assistance. The first thing that naturally suggests itself is to surround the lamp flames with gauze. Let us see how this would work. Suppose the flame thus protected should be introduced into the explosive mixture, what would take place? The gaseous mixture would, of course, pass without hindrance through the gauze, and come in contact with the flame. That portion of gas inside the gauze envelope would explode, and perhaps a number of such small explosions might take place. These would distinctly give the word of danger to the miner. But though the explosions take place within the gauze, the heat necessary to ignite the large mass without is not communicated through it, and the awful results are avoided. This certainly sounds well, but it must be remembered again that it is one thing to speculate on a subject, and often quite another to prove the correctness of the conclusion drawn. In this case, fortunately, the reasoning is correct. A candle or lamp, the flames of which are protected in the manner described, may be lowered into a vessel containing an explosive mixture without danger of explosion. The experiment can be easily tried in the laboratory, and has frequently been made. There is no doubt as regards the result, and hence the problem which confronted us a few minutes since is apparently solved, and by the simplest means. Minor questions may now come up as to the most convenient form of the lamp, &c., but the problem is essentially solved.

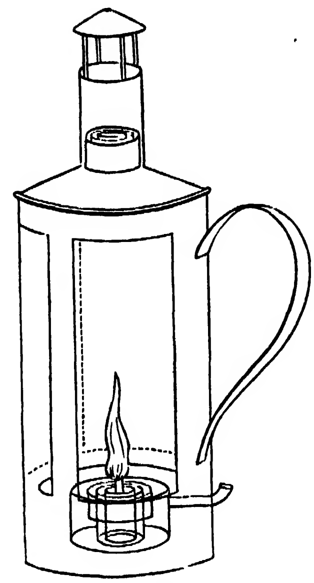

Fig. 6.—The Safety-Lantern, with its Air-Feeder and Chimney, furnished with Safety Metallic Canals. The sides are of horn or glass, made air-tight by putty or cement.

When we consider the simplicity of the lamp we fail to obtain a just idea of the amount of labour which had to be gone through before success was achieved. It is fascinating to turn to-day to the paper of Davy,* in which he gives an account of the experiments he undertook in working out the problem of the safety-lamp. We can become familiar with the workings of his mind, and we cannot fail to admire the beauty of his methods. As we read, our own thoughts keep pace with those of the writer, until

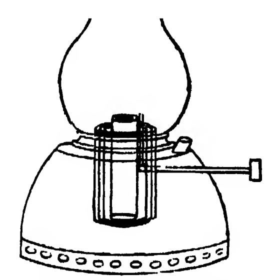

Fig. 7.—An Argand Lamp,

* "Philosophical Transactions of the Royal Society of London," Nov. 9th, 1815.

we can almost imagine ourselves the successful inventors. Here are given some cuts illustrating a few of the different forms of the lamp suggested by Davy. These illustrations are copied from the original paper (Figs. 6—10).

Fig. 8.—A Glass Tube furnished with *FlameSieves*, in which a common Candle may be burnt.

The lamp, in its perfected form, only requires an ideal workman—that is, one who will always think to put his lamp out before he opens it. But workmen become accustomed to danger, and after a time scarcely give it a thought. To prevent accident from thoughtlessness, it has been found necessary to add some attachments to the lamp. These are mainly—first, one which makes it possible to light the lamp without opening it; and, secondly, one which makes it impossible to open the lamp without first extinguishing the flame. In the form in which it is at present commonly used, the lamp is here represented (Fig. 10). It is a stout glass lantern, with wire gauze above, and small openings below to admit the air necessary to keep up the combustion.

It should be mentioned here that at the same time that Davy was engaged in his work, George Stephenson, then an engine-tender in a colliery in Northumberland, was studying the same problem, and that he also succeeded in inventing a safety-lamp, which, in principle, is identical with that of Davy. The lamp illustrated in Fig. 11 is a modification of the Stephenson lamp, the characteristic feature of the latter being the glass cylinder. But it is unnecessary to go into details on this point.* I have desired to make clear the principles of the safety-lamp, and, believing that this has been done, I can leave the subject, with a brief reference to a source of danger in coal-mines which has only recently been recognised.

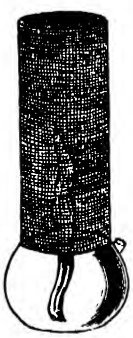

Fig. 9.—A Cylinder of Gauze surrounding a Lamp Flame.

It is known that, in spite of all precautions, explosions do occur in coal-mines. This subject engaged the attention of Mr. Galloway, an inspector of mines in England, and, from his investigations, he came to the conclusion that some connection exists beween the occurrence of these inexplicable explosions and the firing of shot, or blasting. In seventeen out of twenty-two explosions, occurring within a given period, it was shown that a shot had been fired just before the explosions. It appears that the cause of the explosions under these circumstances is the forcing of the flame through the apertures of the gauze of the lamp by the wave of air following the firing of the shot, or the sound-wave, as it is called. Mr. Galloway has shown that certain sound-waves can act in this way. Experiments can easily be performed which prove it. If, for instance, a Davy lamp be placed at one end of a long open tube, and surrounded by an atmosphere of fire-damp and air, and a pistol be fired at the other end of the tube, the flame is driven through the gauze, and the mixture explodes. Of course this result may be avoided by the use of lamps in which the flame is surrounded by a glass cylinder, as in Fig. 11.

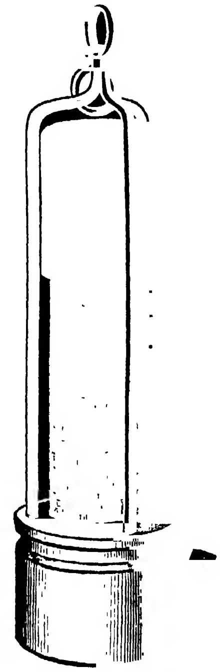

Fig. 10.—The Final Form.

Thus I hope I have shown that there are interesting lessons to be learned from a pool of stagnant water. We started with the simple observation of an occasional bubble rising through such a pool. From this we were led to the study of marshes, and from these to coal-beds. We found that all of these have certain features in common, and that the formation of marsh gas or fire-damp is to be noticed in connection with all of them.

Fig. 11.—Modification of the Stephenson Lamp.

The presence of the fire-damp in the coal-beds was found to be a source of danger to the miner, and how to avert this danger was a question which next occupied our attention. The investigations of Sir Humphry Davy, which led to the invention of the safety-lamp, were then naturally taken up, and the principles upon which the lamp now in use is based were found to be well worthy of consideration.

* The priority of the Davy over the Stephenson lamp and *vice versâ* has been a subject of bitter controversy. In reality each inventor worked independently of the other, and deserves equal credit. Those curious regarding the matter are referred to Dr. Smiles's "Life of Stephenson," pp. 157, 169, 171, 176.

THE OLD LIFE OF EUROPE.

BY PROFESSOR P. MARTIN DUNCAN, F.R.S., ETC.

IF any scientific man had stated, at the time when the great Newton was establishing the solid foundation of celestial and terrestrial physics, that Europe was formerly a howling wilderness, the home of several kinds of elephant, rhinoceros, and hyæna, and the roaming-ground of a lion and of the grizzly bear, he would hardly have been tolerated. Had he expressed his belief that the hippopotamus flourished in Yorkshire, and the reindeer in the south of France, he would have been considered insane. And had such an one written that man then lived as a hunter, that he dwelt in caves and rock shelters, and used rude weapons of stone to get at the marrow of the gigantic beasts he pursued, no language would have been sufficiently strong to be used regarding such folly. In the early part of this century no credence would have been given to the philosopher who asserted that, at a time just prior to that which was the age of the great animals of Europe, the whole of Northern Europe, Northern Asia, and much of North America had a climate resembling Greenland of the present day. And fifty years since, the geologists who asserted that, in a still earlier age, the northern parts of the earth within a few degrees of the pole had a delightful climate and a luxurious vegetation, and that at that time India, Africa, and Europe were united, and had many animals in common, would have been instanced as true examples of the votaries of a pernicious science. Now the doubters of these statements are in the minority, and their truth can be established in the mind of any moderately well-educated person who is competent to argue a little upon the bearings of facts. The struggle between the teachers of these novelties and the exponents of public opinion has been constant and sharp, but it has ended in favour of truth, that is to say, of scientific explanation of well-observed facts. No one doubts that huge kangaroos, of kinds now extinct, lived in Australia before man appeared there; no one discredits the fact that the mastodon, megatherium, and mylodon lived in South America, with many of the existing species of animals. But the cultured European stood aghast at the discovery of similar facts, which entailed the belief in the great antiquity of the human race in Europe, and the contemporaneity of man and extinct animals. Take a common instance of the acceptation of the discovery of the remains of huge animals. The ancient town of Colchester has beautiful relics of mediæval art; still earlier Norman architecture is to be seen, and the walls are of Roman age. There are Roman burial-grounds on the west of the town, and monuments, inscriptions, and coins testify to the former presence of a foreign and conquering race. Here and there, beneath the relics of the Roman occupation, rude pottery is found, bronze weapons are discovered, and also bronze and gold coins. These relate to the kings who reigned before the Roman Conquest. Occasionally rude stone weapons, polished on the surface, are found, and they denote a still earlier race.

Now, about one mile and a half from the town, a clay deposit exists on a hill-side of the valley of the Colne, and in that clay teeth of elephants were discovered, and many insect-remains. The classical scholars soon proved that the Romans used elephants in war, and, although the proofs were wanting, they asserted that Cæsar brought the great animals over with him. This unscientific explanation of the fact satisfied most of the people who had preconceived opinions, and had conscientious objections to elephants being dwellers in England. But the teeth of the elephants, when even superficially examined, were noticed to differ in shape, and in their details of construction, from those of the Indian or African elephant. There were two kinds, moreover. This was a puzzle, and then the insects were not like those of temperate climates. By-and-by excavation brought up bones of the hippopotamus, an animal which certainly did not come over with the Romans. The scientific explanation was that the possessors of the teeth and bones, and the former owners of the pretty wings, lived near where they died; that the bones and teeth had been brought down by floods when the country presented a different appearance to its present configuration—in fact, before the valleys were as deep as they are now.

England and Europe are within a natural-history or distributional province, called the Palæarctic province, and it comprises the whole of Europe and Asia, with the exception of the vast countries

environed by the curve of mountains of Sind, Afghanistan, and the Himalayas. It is bounded by a line through China, and it includes Japan. Moreover, it is necessary to add to this great space the North of Africa, Northern Arabia, and Persia. This region is subdivided by Mr. Wallace as follows: The first sub-region is the European, and it contains Europe, limited to the south by the Pyrenees, the maritime and Swiss Alps, and the Alpine chain which is south of the Danube, and the Balkans, the Black Sea, and the Caucasus; the boundary to the east may be said to be the Ural Mountains and the Caspian Sea. The second sub-region is the "Mediterranean," and it comprises South Europe, North Africa, with the extra-tropical part of the Sahara region, and Egypt to about the first or second cataract on the Nile; and it extends eastward, through Asia Minor, Persia, and Cabul to the Indus. The third, or Siberian sub-region, consists of all North and Central Asia, north of Herat, as far as the eastern limits of the great plateau of Mongolia, and southward to about the upper limit of trees in the Himalayas. The fourth, or Manchurian sub-region, consists of Japan and North China, with the lower valley of the Amoor; and it should probably be extended westward in a narrow slip along the Himalayas, embracing about 1,000 or 2,000 feet of vertical distance below the upper limits of trees, till it meets an eastern extension of the Mediterranean sub-region a little beyond Simla.

A glance at a map will show how varied is the physical geography of this province, and a little reading will discover what different climates there are in it. In the sub-region of Europe, there are the mountainous districts of the Alps, the table-lands of Central France, the broad valleys of the Rhine and Danube. There are the swamps and lakes of the North, the vast plains of Russia, the cold hills of the extreme North, and all the varied scenery of the British Islands. Some of this great district is within the Arctic circle, and some never, or very rarely, is exposed to frost. Geology proves that these varied scenes are comparatively new; that the sea has worn the land, separating islands; that the pluvial and fluviatile denudations have been vast since man has roamed over the country; and that in the last age, ice reigned supreme down to the latitude of the Thames. The present assemblage of animals is the outcome of a former one, and it has diminished in numbers with the progress of civilisation. Hence, the questions arising out of the distribution of animals in Europe are complicated, and different from those which have been referred to in the countries of Australia and South America.

The unity of the Palæarctic province, which contains Europe, is shown by the fact that, in spite of man and his influence on animal distribution, there are three families of vertebrata and thirty-five genera of mammalia peculiar to it, and which are not found in any other of the provinces of the world. Moreover, the absence of the peculiar animals of the other provinces is very remarkable, and indicates that a considerable separation has existed for long periods of time—for as long as the physical barriers which separate the provinces have been in existence. Some of these barriers are deserts, and others are high mountains, rivers, and seas, and, as a whole, the province is not limited so perfectly as the Australian (Vol. IV., p. 334) or the Austro-Columbian—the South American (Vol. V., p. 203).

The provinces to the south of the Palæarctic are the Oriental and the African, and they are much better limited by nature. The result is that they have more peculiar and characteristic animals than the region which comprises Europe; but they have not so many as Australia and South America.

The striped hyæna is a member of the assemblage of animals within the Palæarctic province, for it inhabits Africa north of the Sahara, Asia Minor, and Persia. The other hyænas are the spotted and brown kinds, and the first ranges all over Africa south of the Sahara desert, the latter being more restricted to the south, so that they are at the present time not animals belonging to the European division of the Palæarctic province. Now, in the last geological age, and contemporaneous with early man, these two species, or slight varieties of them, lived high up in Europe, and one of them flourished in this country. There was a hyæna which frequented caves, and lived on the carcases of dead animals. It was a great gnawer of bones, and made collections of them for the future study of the geologist. It is called the cave hyæna (*Hyæna spelæa*); but it is only a variety of the spotted kind, which now is South African in its home. The striped hyæna also lived in Europe, but in smaller numbers, and its fossil remains have been found in Gibraltar.

There is no doubt that a large animal, which ought to be classed with the other members of the group Felidæ (cats), lived in Europe, roaming over England and as far south as Gibraltar and east into Germany, and preyed on the young elks, deer, and bisons of its day. Cuvier described the remains

first of all, and called them *Felis antiqua;* and Dr. Falconer, years afterwards, recognised them as belonging to the modern panther and leopard, and thus associated another living form of beast of prey of African and Eastern distribution with the hyæna of Old Europe. At the present time the *Felis pardus*—the panther and leopard—is found in the warm regions of Africa and of Asia, and beyond the European province.

Remains of smaller cats have been found in the caves and river deposits of England and Europe, and one set belongs to the common wild cat (*Felis catus*); but other bones are not those of that widely distributed living species. Professor Boyd Dawkins, after careful comparison, decides that these bones once belonged to a living cat resembling *Felis caffer* of Africa. Hence another element of the African fauna was in Europe during the last geological age, associated with the other great predaceous animals.

The remains of a very large beast of prey have been found in England and on the continent of Europe. It was characterised by the possession of enormous upper canines, or "dog-teeth," and they were flat instead of rounded, sharp at the tips, and marked by saw-like edges on the sides. These teeth projected downwards by the sides of the lower jaw, and must have been terrible instruments of destruction. Their length is nearly six inches, and they were carried by a powerful jaw. They are bent, and being flat they resemble a sabre in shape, and hence the name, sabre-toothed carnivore, which has been given to this animal. It has the number and (with the exception of the canines) the same arrangement of the teeth as in the genus Felis, to which the lion and cat belong; but it was not one of them, and it is placed in the genus Machærodus. There was a species of it that roamed over Europe, but not in the northern countries, in the age before the Glacial period, and at that time. During the early Pliocene age other kinds lived in India, in the Oriental province; and in the South American province a Machærodus was found with the remains of the extinct ground sloth. The genus Machærodus had, then, species closely resembling one another, and it had a very wide geographical range. Living in Europe before the Glacial period, it had also a species which preyed on the deer and oxen of the age after that epoch of cold. This left its teeth in Kent's Cavern, near Torquay. But large and strong as was Machærodus it died out, and there are no traces of it to be found during the later ages when man used smooth stone implements, and had domestic animals. Oddly enough, the specimen discovered in Kent's Cavern was found to have been gnawed by hyænas, and there is evidence to prove that early man lived in the dangerous neighbourhood of this great cat, which was neither lion nor tiger, but had their habits.

At the present time the lion is a member of the fauna of the Palæarctic province, for it is found in North Africa north of the Sahara, and in Persia; but it is not a characteristic form, on account of its being found in Africa south of the Sahara, in another province. Very probably the lion had a wider range in the Palæarctic province in the historic period, for it is said that Xerxes encountered the animal in Thrace before the battle of Thermopylæ. But there are no proofs of its occurring, since men have written histories, in any other part of the European division of the great province than the country south of the Balkans. It has not been noticed in Italy or Spain, for instance.

About the year 1672, a Dr. John Hain wrote a book about the dragons of the Carpathian Mountains, and drew the figure of a finger-bone of an animal which he had found fossil. In 1749 Leibnitz figured the skull of a beast of prey, which had been discovered in the cavern of Schartzfeldt, and considered it a part of an elephant; and in 1776 an upper jaw of a beast of prey, differing from the bears, was noticed by Esper, from the cave of Gailenreuth.

Other German authors followed, and Goldfuss in 1810 described similar remains, and he stated that they belonged to a cave lion, *Felis spelæa.* This great beast of prey left its remains in the river gravels and caves of Hungary, Germany, Belgium, and France. Its bones have been found in extraordinary numbers in West Somerset and Wilts; bones and teeth have been found wherever there are important caves and river deposits in the North Riding of Yorkshire. It has been found in the Eastern Counties; in the valley of the Thames; near Salisbury; in the valley of the Avon; on Durdham Down, and especially in the western half of the Mendip Hills. The cave lion has not been found in Scotland, in the northern counties, nor in Ireland.

As the science of Comparative Anatomy progressed and as the specimens of *Felis spelæa* have been compared with those of the modern lion or *Felis Leo,* the identity of the two forms has become established as a fact. Hence, in the last geological

epoch, the lion, now restricted to the extreme south-east and part of the south of the Palæarctic province, roamed over England and Europe south of Denmark and Prussia. It was the destroyer of the multitude of herbivorous animals of the time, and the fellow-hunter of the panther and hyæna, and it competed with Machærodus. The lion has therefore a great antiquity, and had once a vast range. Probably it extended into North America during the last geological age, but it is not represented there by a living descendant. Before the Glacial period, the lion did not exist in Great Britain, and probably it came there on the retreat of the ice and cold, travelling northwards and westwards after its prey.

The lynx is one of the predaceous animals of the Palæarctic province, and there are two varieties of it, which live in Northern and Central Europe, and a third in the South. It clings to the forest-side, and holds its sway in wild districts, destroying sheep. It is one of those animals which, like the reindeer, are more characteristic of a great circumpolar continent than of the Palæarctic province; for a variety, the Canadian lynx, exists in the North American province. Nevertheless the lynx is not an animal which can swim far, and is not one of the beasts of prey of this country. Formerly the animal had a greater range. It left its remains in European caves, and in Derbyshire also. It formed one of the enormous assemblage of animals which existed after the close of the great age of ice, and it must have got into England by land with many of the other beasts of prey and herbivora. It does not appear to have lived on our area previously to the Glacial period.

The wolf still lives in continental Europe, but it was gradually hunted down in the United Kingdom; its habits are well known, and there are several geographical varieties of it. Its more astute fellow, the fox, has as wide a range, indeed wider, for it still lives in England, Scotland, and Ireland. Both of these predaceous animals roamed over the same ground during the last geological age, and their remains are common in many an English cave and river deposit. They are animals of considerable geological antiquity, and their type has lasted during more than one great change in the physical geography of the world.

Amongst the few remaining beasts of prey of any great size, of the Palæarctic province, are the bears. The brown bear is the commonest, and is still found in Northern and Central Europe, Spain, and in the Eastern or Siberian division of the great province. Like the wolf, it has been hunted down in the United Kingdom, and, moreover, it had a similar antiquity, for it lived during the last geological age in England and also over its present roaming-ground on the Continent. But there were other bears in Europe during the time when the caves were formed by natural drainage and the gravels of the valleys were being worn and deposited, and one of them was very remarkable on account of its present distribution.

The grizzly bear (*Ursus ferox*) is a North American animal, and has never been found living in the Palæarctic province. In the caves of England, and in some parts of the Continent, bones, skulls, and teeth have been discovered, which cannot be distinguished from those of this great and very destructive creature, which is the terror of the wilds of the far West of the United States. Another bear, as large as the "grizzly," lived with it, but it became extinct everywhere. The name of it is the cave bear, or *Ursus spelæus.*

The glutton, marten, badger, and weasel are predaceous carnivora, well known in the Palæarctic province, and they lived in the last geological age, and have descended without any modification. All that can be said about them is, that their roaming-grounds have diminished and they are more restricted to certain parts of the great province than before. The otter, which has been found in the fossil condition, of course was the predecessor of those which now live, and the same may be said of the water-rats and other small animals.

The Romans obtained elephants of the large-eared kind from Northern Africa, and therefore within the great Palæarctic province; and this African elephant, as it is now called, once lived in Spain, just before the historic period; now it is extinct in North Africa and also in Spain. The separation of North Africa and Spain took place during the lifetime of this species, which is now only found in tropical Africa south of the desert. Three kinds of elephants, all now extinct, were living in Western Europe and England before the Glacial period set in with prolonged severity; and two of them, driven south by the cold, returned afterwards and lived with man. They were the Southern elephant, or *Elephas meridionalis*, with coarse teeth; the Ancient elephant (*Elephas antiquus*), which is a descendant of an elephant now extinct, that lived at the same time, and earlier in India, and which is called *Elephas nomadicus;* and the Mammoth, or *Elephas primigenius*, is the third.

It is not difficult to imagine the feelings of wonder with which some of the native hunters of Siberia saw a huge animal, with tusks and a woolly hide, exposed by the fall of a cliff at the mouth of the river Lena. Placed nearly in the erect position, this animal, entirely unknown to them, was all the more strange from its being enveloped by ice. As the summer passed away the carcase became more and more exposed, and wolves and other animals consumed most of its flesh. But the skeleton and much of the skin and hair were preserved, and are in a museum at St. Petersburg.

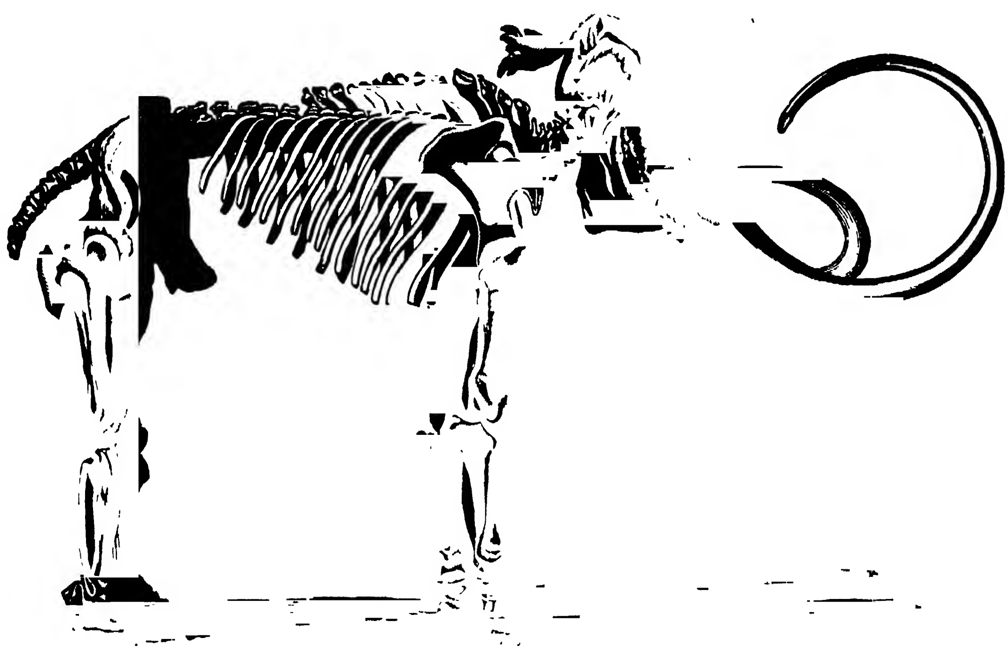

Fig. 1.—Skeleton of Mammoth (*Elephas primigenius*).

The creature was a large elephant, with long curved tusks; and the skin, instead of being like that of the Indian and African elephants of the present time, was woolly, or rather was covered with close short hair. An examination of the teeth and bones satisfied anatomists that this skeleton belonged to an extinct species of elephant, the remains of which had been discovered previously in Europe and in this country. It was an elephant with more than usually long and curved tusks some nine feet and a half to eleven feet in length and two feet and a half in circumference at the thickest part, and with the teeth not differing much from those of the existing Indian elephant. Such was the mammoth, or *Elephas primigenius* (Fig. 1). This creature had a most extraordinary geographical range, and as a species it lived during an enormous period of time, geologically speaking. It wandered out of one distributional province into another, and seems to have cared little for physical limits, which at the present time interfere with the range of elephants; or rather it lived so long as a species that it survived great changes in physical geography and climate. The mammoth, recognised by its teeth and bones, lived in the South of Europe, in the Roman district, in the North of Spain, and vast herds must have existed in France. Its remains abound in Germany and in North-east Russia, the Ural Mountains, and, as has been mentioned, in Siberia. It has not been discovered in Denmark or Scandinavia; but there were multitudes in England, and some roamed over Scotland and Ireland. There are great numbers of teeth of *Elephas primigenius*, which have come from cliffs, which give out a powerful scent of decomposition during the hot weather, in Eschscholtz Bay, in Behring Strait, and others have been found here and there in North America, as far south as the Isthmus of Panama. As the animal could not possibly cross from England to Ireland, from England to the Continent, and from Asia to North America, over the straits, it follows that the separation of those lands has occurred since the first appearance of the mammoth. Whether the hairy coat was present in all the mammoths is a matter of speculation, but certainly the coat of the Siberian mammoth would have been very useful to it in a temperate climate when the frost

was not very severe. The elephant of to-day requires water and succulent food, and experience teaches that it will live where there is frost at night. The stomach of the frozen mammoth, examined by the botanist, contained leaves of grass and of pine-trees, but probably this was the food of a starving beast, which had wandered as the climate was growing more and more severe. From the positions in and under clays and ice-borne deposits, and in river gravels, in which the mammoth remains have been found, it appears that the species must have lived during a warm and genial time; during a subsequent period, when the average temperature of the northern hemisphere diminished; and, finally, that it witnessed a partial restoration of the former state of things, and died out during the excavation of the present river valleys. The mammoth lived in Europe and America—in two natural history provinces, before the Glacial period; it flourished in an inter-glacial time, and, driven south as the ice and snow covered much of its country, it again returned to its former grounds. But in these long ages the geographical changes were progressing which produced the present limits of the distributional provinces. The mammoth lived at the same time as early man, and it died out before the historic period. No wild elephant has lived in Europe during the historic period, but some are recorded to have been hunted in the region around Nineveh sixteen centuries before Christ. The Indian elephant does not pass beyond the Himalayas and the Indus, nor does the African elephant pass out of that continent. But the African elephant did live in Spain in the last geological epoch—that just preceding the prehistoric period, when men had domestic animals. What were the elephants, then, which were chased by Tothmes III. in the valley of the Euphrates? An elephant, somewhat resembling the mammoth, lived with man in the savage state in Asia Minor, and is called *Elephas armeniacus*, the Armenian elephant. It is extinct, and it was, in its structure, intermediate between the present Indian elephant and the mammoth. It is, therefore, very probable that the elephants of India are related to the ancient extinct elephants of the distributional province which includes Europe and Northern Asia. Several varieties of the mammoth existed in North America, but they appear to have passed away as man began to dominate there. The "Ancient Elephant" (*Elephas antiquus*) was a more slender animal than the mammoth, and did not reach so far north or west as this very hardy creature did. Its remains are found in deposits which accumulated before and after the Glacial period, and it became extinct before the days of metals and domestic animals. The Southern elephant, *Elephas meridionalis*, was the relic of an earlier assemblage of animals and did not survive the age of cold.

Contrasting with the dimensions of these great elephants were others whose remains have been found in the island of Malta, which is within one of the great divisions of the Palæarctic province. The fossil *Elephas melitensis* was a pigmy not more than four feet and a half in height, and another was even smaller than this. They lived when Malta was united to Sicily, and their companions were huge tortoises and birds of great size.

There were elephantine creatures living in Europe before the Glacial period, called, from the peculiar shape of their grinders, Mastodons; and one species roamed in North America, lasting there through the age of ice, and living probably contemporaneously with man. Like the elephants, the mastodon flourished in India, but it is now extinct everywhere.

The next group of animals have no modern representatives in the Palæarctic province, for the rhinoceros family are quite foreign to it. But living in Europe, contemporaneously with early man, were several kinds of rhinoceros, and those which now exist in India, Java, Sumatra, and Africa were not of the species which left their bones in the remote north, east, and west of the ancient Europeo-Asian province, termed Palæarctic. The first extinct

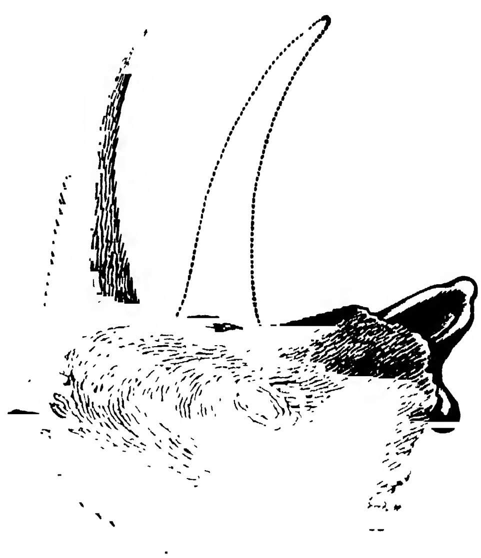

Fig. 2.—Skull of the Woolly Rhinoceros (*R. tichorhinus*), partly restored.

rhinoceros was found in Siberia under similar conditions to the mammoth, and, singularly enough, it was a woolly creature. It ranged as widely as the mammoth did in Europe, but it did not live on the American continent. It is called *Rhinoceros tichorhinus*, and its nose carried two horns, and its nostrils had a stout partition to strengthen the bones above (Fig. 2). Another two-horned rhinoceros lived in France, Italy, and England before the Glacial period. It seems to have lasted out that great age, and to have left its bones in the flood-earth of the Thames. Other species were the rhinoceros with large front teeth; the Etruscan rhinoceros and the Leptorhine species, which had a very delicate nostril-bone. These were all European, and mostly British animals; but now the genus is restricted to the warmer climates of the Old World, in other provinces.

The hippopotamus is now restricted to the alluvial districts of tropical Africa. Formerly, both before and after the Glacial period, the hippopotamus, and probably the same species that now lives, roamed over France and England as far north as the Ribble.

The moles constituting the genus Talpa are characteristic of the Palæarctic province, and some species or other is found from Great Britain to Japan.

The European beaver, *Castor fiber*, differs slightly from the American, and is confined to the temperate regions of the Palæarctic province. Once it was not uncommon, but the advance of agriculture and the arts of civilisation have driven it into very remote districts. There are no beavers in this country. Dormice have the same range as the moles, but a rat genus is found in Africa.

In the group of ruminating animals, the chamois is a characteristic Palæarctic animal, and maintains its ground in the Pyrenees, Alps, and east to the Caucasus. The oxen and buffaloes of the genera Bos and Bison roamed in vast numbers over Central Europe and eastwards in the early historic period. The original species of ox is restricted to a few localities now, and the bison, of a different species to the American, is found wild in Poland and the Caucasus.

The common mole lived in the last geological ages, and it has been found fossil below the deposits which are of Glacial age, in the inter-glacial deposits, and in caves and river gravels; but the old forms do not appear to have differed much from those which now dig and burrow in the ground. Beavers lived during the post-glacial age, and in that of the Pliocene, and some of them were large and of a different type to the existing. Trogontherium is the most common genus of the extinct beavers.

Dormice have been found fossil in all the Tertiary deposits of Europe, except the Glacial, and there was a very large form living in Malta during the Pliocene age. There was a fine ox which lived during the latter geological period, *Bos primigenius*, and it was doubtless the progenitor of the present cattle. In the Pliocene age, and probably in the Miocene time, a thick-set camelopard lived in the South of France, Greece, and Western India. It became extinct, and is interesting as one of the former links between the Oriental, Ethiopian, and Palæarctic faunas in the olden time.

The red deer is a characteristic animal of the province now under consideration, but the reindeer roams over all the North American area in high latitudes. Both lived in days of caves and valley gravels, and the latter existed in vast herds in the West of Europe as far south as the Alps. They were hunted by man and hyænas in England.

The Irish elk, *Cervus megaceros*, a huge animal, lived formerly in Ireland and England, but became extinct before the historic period.

The wild horse is found in the Siberian division of the province, and the fossil remains of it are discovered throughout the whole province, and are very numerous.

Another of the animals which roamed over parts of England and Europe, and which, although extinct in the Old World, still survives in the New, is the musk ox, or musk sheep (Fig. 3), for anatomists differ about its zoological position. The first trace of the animal in the Palæarctic province was found in Siberia, in a barren, treeless ground near the river Obi. Two skulls were discovered by a celebrated Russian naturalist, Pallas; but Tanners, an English naturalist, first distinguished them as those of musk oxen, in 1784, and stated that the animals, now restricted to the North American continent, formerly lived in Northern Asia. Then the remains of the *Ovibos moschatus*, for that is the scientific name, were found in Europe, in Prussia, and years afterwards farther to the south. Rather more than twenty years ago the teeth and skull of individuals of the species were found in the river gravels of the Oise, and subsequently others were discovered in Perigord in Auvergne. Sir John Lubbock and Canon Kingsley found a skull in the gravel of

the Thames, at Maidenhead, in 1855; and a portion of one at Bromley, in Kent. Then Mr. Charles More, of Bath, found specimens in the valley of the Avon, and other observers discovered them in the gravels of the Severn and of the river near Salisbury, and at Crayford, in the lower part of the valley of the Thames. Evidently the *Ovibos* had a considerable roaming-ground, and researches have proved that it is an ancient North American animal. Remains have been found in Eschscholtz Bay, on the western coast of North America, in river gravels; so that this long-haired, big-headed, curly-horned, short-tailed, ox-looking sheep, with unsymmetrical hoofs, smelling of musk, is as remarkable as the reindeer in its former distribution. The associates of the old musk oxen in Europe were those of the reindeer; and in the Auvergne the animal certainly was hunted by the aborigines. At the present time these animals, which are about the size of small Welsh cattle, are restricted to parts of North America, north of 60° N. lat. on the east, north of the 66th parallel more to the west, and farther north in the extreme west of the continent. It ranges from the river Mackenzie, or perhaps much farther westward, across the vast continent to Melville Island, and across Smith's Sound to East Greenland, north of Franz Josef Fjord. They are also found in North and West Greenland, but never south of the glaciers of Melville Bay. In Danish Greenland "umingmak" is only a tradition. They are gregarious in habit, forming often large herds; and they like difficult stony ground, climbing rocks as easily as a goat. Feeding on grass when it is to be got, they will live on moss and the leaves of the tops of the small willows at other times. They migrate and are essentially Arctic animals.

Iusk "Oxen" or Sheep (*Ovibos moschatus*).

It will have been observed that none of the marsupials or the edentata, the characteristic animals of the Australian and South American provinces, lived in the Palæarctic province during the last geological age. Did this description relate to earlier days this remarkable story could not be told; but, dealing with the days before, during, and after the Glacial period, it may be said that the ancient animals of the Palæarctic province (as now limited) consisted of European, Asiatic, African, and North American types. The whole assemblage is a curious jumble of forms, many of which became extinct, and were not ancestral to any kinds now living on the area; there were others which are represented by the same species in the regions of the North of Europe, Asia, and America; others which live in the tropical districts of Africa; and some which have lasted on to the present day, and are still characteristic animals of the province. The simplicity of the succession of the same types, witnessed in the Australian and South American provinces, is not recognised in the Palæarctic province, and the reason why relates to the great geographical changes which occurred during a period of increasing cold, to the Glacial age, to times of decreasing cold, and to the age of the wearing down of the valleys.

IS THERE COAL UNDER LONDON?

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IN two previous papers in the present volume (pp. 234, 298) I have endeavoured to supply the reader with the elementary information, and to lead him through the preliminary reasoning, necessary for the attack on this question. I have shown what there is beneath London for a thousand feet down, namely, Tertiary and Secondary Rocks in regular series so far, and I have shown that a coal-field *may* be concealed beneath Secondary Rocks resting unconformably on the edges of the coal-bearing strata. We have now to look at the results of the very deepest explorations that have been made beneath London, and it will soon be seen that although these have descended but one or two hundred feet below our thousand, yet they have yielded most important information.

It must be premised that all the explorations beneath London hitherto made have been for the sake of *water*. The arrangement of strata beneath and around the capital is such that a supply of water trickling down and collecting from a large area has always been expected, and has often resulted, from a fairly deep well-sinking or boring. The arrangement is generally described as a basin. As was explained in the paper, "What is under London?" the beds *dip up* southwards and northwards, and ultimately westwards also. The chalk, with its great thickness, when it has thus come to the surface, occupies a wide area, and it makes hills rising to 500 and 600 feet above the level of the valley in which London stands. Resting, as it does, on a continuous impervious bed of clay, the Gault, it retains the rain-water that falls on it, for this, in filtering down through the mass of the chalk, can descend straight only so far as to the top of the Gault, and will then tend to flow *along* in the direction of the dip, and collect in the interstices of the chalk in the hollow of the basin of strata. As the water thus accumulates it will rise to a higher and higher level until some outlet is reached; in this case there is the line of the outcrop of the top of the Gault, which occurs along the foot of the chalk hills on the south and on the north. Along that line, or a little above the level of it (from the bottom beds of the chalk itself also being more or less impervious), occur a number of springs, which are the overflowing of this underground water. An Artesian well consists in the tapping of the underground reservoir towards the central part of the basin. According as fissures occur in the rock a communication with such a reservoir will be made earlier or later; but when it is made, water will rise in the well or the bore-hole to a level corresponding to the height of the water around the edge of the basin. In this way large supplies of water have been obtained. To give one instance: near Chalk Farm the Tertiary beds were penetrated, and then 160 feet of chalk were passed through; total depth, 400 feet; and then the water rose to a level only 160 feet from the surface. But, with a rapidly-increasing population, it is not easy to make the supply of pure water keep pace with the demand; and for another reason engineers have wished to draw on different sources for water. That which comes from the chalk is *hard*, that is to say, it is wasteful for washing, destroying a certain amount of soap before a lather is obtained; and the same quality makes it incrust boilers where it may be used; the reason in both cases being that it contains much lime, in the form chiefly of bicarbonate, dissolved out of the chalk. Hence, for many years, designs have been entertained of obtaining water from a lower and a purer source.

And, indeed, the structure of the country beyond that which we have thus far surveyed has held out hopes of success; for beyond the outcrop of the Gault, in Surrey and Kent on the one hand, and in Buckinghamshire on the other, there comes a tract of sand, which is the outcrop of the Lower Greensand, a good thick stratum of permeable material, and this is succeeded on the surface, and underlain, by impervious clay beds. If, then, these continued beneath the whole of the basin area, they would give a second and even a better chance for an Artesian water-supply. This Lower Greensand on its southern outcrop is well known to the writer, and it would repay any one who should take the trouble to make its acquaintance, for it constitutes some of the prettiest ground in the South of England. The nearest point to London where the sand comes to the surface is just short of Redhill, and it can always be seen in the railway cutting beyond Red-

hill Station. The formation makes a line of hill roughly parallel to, and a few miles south of, the chalk escarpment, running eastwards into Kent, which county it enters near Westerham, and westwards right across the southern part of Surrey. The thickness of the formation is 400 feet. The upper part of this is of loose yellow sand, with irony matter sometimes cementing or colouring the sand in irregular wavy lines; in the middle portion there is generally some more or less clayey matter, while the bottom part is more stony. The stone occurring at this stratum-level is either a sandstone, as at Godstone and at Leith Hill; a calcareous sandstone, as at Godalming (where it is called "Bargate Stone"); or, to the eastward, in Mid-Kent, a limestone—Kentish Rag—with sand layers between. It is the great spread of country occupied by the Lower Greensand, and the considerable height above the sea-level to which it reaches, and its extremely porous character, as well as its position underground between two impervious layers, that constituted a strong probability of its holding a goodly store of water beneath the London basin, which store should be opened whenever the Gault was penetrated.

The first time this was done, disappointment was the result. At Kentish Town, about five-and-twenty years ago, a boring was made to a depth of 1,300 feet; after the chalk and 60 feet of Gault were penetrated, instead of the loose yellow sands of the Lower Greensand formation, the borer entered some red sandy rock, the age of which is even now not known for certain, and about which opinion at the time wavered between Old Red Sandstone, New Red Sandstone, and Wealden. The first of these opinions now seems the most likely. In any case, it was clear that the Lower Greensand did not exist where it had been expected, and as the whole argument in favour of water being found in large quantities rested on the supposed continuity of that formation, geologists could no longer recommend the adoption of the Artesian principle to the extent of sinking below the chalk.

There is no doubt that at that time most geologists were surprised at the result of the Kentish Town boring, for although sand is the kind of sedimentary rock most likely to vary in thickness, being a shallow-water, and often a near-shore, deposit, still it was unlikely that such a considerable thickness as we have seen to occur in Surrey, of which the character of at all events the upper portion was so unchanging, should in the 20 miles between Redhill and London have altogether thinned out.

But there was one geologist who, reasoning on data drawn from far and wide, had, a short time before this boring was made, predicted that the various Secondary rocks would thin away as they approached London, and had propounded the theory that the older Palæozoic rocks, including the Coal Measures, occur at an available depth beneath the home counties (Essex, Herts, Middlesex, Kent, Surrey, Sussex). This was Mr. Godwin-Austen, who in 1856, before the Kentish Town boring had been made, put his views before the Geological Society, in a paper entitled—"On the possible extension of the Coal Measures beneath the south-eastern part of England."

Our insularity of position and of habits has undoubtedly affected the geological views of some of us; and in this case we might have more quickly got on the right scent had not our geological maps and treatises so generally ended their descriptions at our shores. On the English coast, at the south-eastern corner of the island, between Rye and Deal, there is seen more or less clearly a great thickness of Secondary rocks conformable one to another, consisting of Wealden beds, Lower Greensand, Gault, Upper Greensand, and Chalk, of a total thickness of over 2,000 feet; and besides this, a late boring begun on the outcrop of the base of the Wealden went through 2,000 feet more of Secondary rocks, with no signs of approach to the Palæozoic strata. Yet within sight almost of Folkestone, ten miles only inland from Boulogne, are to be seen on the surface indisputable thick bedded limestones of Carboniferous age, resembling closely that described (Vol. I., p. 12) as occurring in Derbyshire, and constituting the lowest member of the Carboniferous series. Besides this there occur Devonian rocks next below that limestone, and Coal Measures above it; in fact, not more than fifteen miles from Boulogne are coal-pits, where coal is got at small depths.

The relation existing between the lower rocks and the Secondary it is not difficult there to make out. At different spots different formations, of the Jurassic and Cretaceous series, rest unconformably upon the Carboniferous and Devonian beds. Marquise, eight miles from Boulogne, is a town whence these places can easily be visited. The Carboniferous limestone is seen in certain valleys which have been cut down below the general level of the country, and has at several spots been worked out for the sake of the stone, some of the layers of which afford a marble a good deal sought after. The column reared on the plateau behind Boulogne to Napoleon I. by the Grand Army, while awaiting

orders to embark for the invasion of England, is made of marble from these beds: the same material is now exported to England for marble-topped wash-stands and tables. From the evidence afforded by the quarries it is evident that the highly disturbed Palæozoic strata were in Jurassic and Cretaceous times planed off, and that they came to be covered with the material accumulated during those periods. The fact of their being covered in places by a Jurassic bed and in places by a Cretaceous bed, implies that in Jurassic times the area was only partly covered by the sea, but that as time went on to the next period it became completely covered. In other words, the lower Secondary strata thinned out and were overlapped by the higher, through the gradual encroachment of the sea upon the land, aided by depression of the land. By the time of the Gault the whole had been covered by the sea, for the Gault is continuous around the area we are now describing. Boulogne is the centre of a curve of chalk hills, distant from it ten to fifteen miles, which is an escarpment exactly corresponding in form and structure to the escarpments of the North and South Downs, there being always at the base of the steep chalk slope the outcrop of the blue clay, which the French geologists also call Gault, occupying a width of a mile, more or less, corresponding to the usual thickness of 100 feet. This area within the chalk escarpment is called the Bas Boulonnais; it contains, as will have been seen, the outcrop of a much greater variety of formations than the corresponding one on the English side of the Channel.

It was from these facts, and from others observed farther east, that Mr. Godwin-Austen drew the inferences before alluded to, and endeavoured to ascertain the extent and the composition of the Palæozoic "floor" of Secondary times, which same question still occupies geologists, who are gradually making progress in their knowledge of it. The first point for determination is whether the Coal Measures proper (*i.e.*, the sandstones and the shale, with coal) extended over the area of the home counties, or whether some other form of deposit may not have taken their place, or even such land have existed as did not allow of the growth of coal forests; that is to say, the conditions necessary for the finding of coal beneath London are that the Coal Measures in their formation once extended there, and that in the later upheavals and denudations, some portions of them, sufficient to make a coal-field, have been preserved.

For the ascertainment of this first condition, we will look at various coal-fields in England and at the thickness of their strata. Beginning with the one we examined in detail—the Chesterfield coal-field—we there saw 3,000 feet of Coal Measures, the middle part of which contains workable beds of coal. On the western side of the Derbyshire hills (the southern end of the Pennine chain), are the Lancashire coal-field and the North Staffordshire coal-field, with a still greater thickness; of these, some of the beds correspond with the beds on the other side of the range, both grit and coal being recognised bed for bed. There can be no doubt at all that the Coal Measures continued across; that is, that there was, in the Upper Carboniferous period, one level floor of sedimentary deposits covered at various times by coal-producing forests, extending across England from, at all events, Flint to Lincoln. Not far south of this comes a group of coal-fields, in Shropshire, South Staffordshire, Warwick, and Leicestershire, which, Sir Andrew Ramsay tells us, were all originally formed as one coal-field, and even now in great part may be continuous in the districts that lie between, concealed by Permian and New Red Sandstone strata. But it is worthy of note that in some of these we have signs of the bounds of the Carboniferous sea, since the Coal Measures are in places found resting on Upper Silurian beds without the intervention of the Carboniferous limestone. A new fact that throws light on the further extension of Carboniferous rocks is the finding beneath the oolites, &c., at Northampton, of limestone with Carboniferous fossils; this at a depth of 900 feet. Taking this as in or near a line of upheaval stretching from Derby, by Charnwood Forest in Leicestershire, we might then expect the Coal Measures of the Warwickshire coal-field to continue beneath Rugby and Daventry, and possibly on in the direction of Buckingham.

The argument for the continuation of the coal is that such a great thickness of strata as the Coal Measures—reckoned as it is in thousands of feet—cannot end off suddenly; it must either thin out (first probably changing its character) seawards, or must have its strata over-lapped, lower ones by higher ones, on the shore side, *and then we should find traces of yet older land.* This we do in some parts, as above mentioned, but there must have been a wide stretch between Charnwood Forest and the Herefordshire hills, which, in Coal Measure times, was receiving strata that allowed of the formation of coal, and it is the

southern extension of this coal-bearing area that has to be ascertained.

The southern group of coal-fields is of equal importance to our argument. From Pembrokeshire to Pontypool, in Monmouth, is one connected stretch of Coal Measures, which attain the thickness of 10,000 or 12,000 feet, with about one hundred beds of coal. This is the South Wales coal-field. Next is the small oval coal-basin of the Forest of Dean, which Sir A. Ramsay describes as an outlier of the South Wales field; here the coal-beds are twenty-three in number, among strata something under 3,000 feet thick, the higher beds having been worn away. South of this is the Bristol coal-field, a basin much hidden by unconformable Secondary rocks; here, according to the same authority, are forty-six beds of coal, in 7,000 feet thickness of Coal Measures. No one can doubt that these three coal-fields were once united, and that the 7,000 feet of the last-named once extended far eastwards. Thus, from two starting-points, the Warwickshire and the Bristol coal-fields, about 100 miles on the north-west and on the west of London, we have reason to expect a considerable extension of the coal-bearing beds towards the metropolis; and a fact has lately come to light which has given us some positive evidence of this. At Burford, in Oxfordshire, not far from Witney, a place situated on the oolitic beds, and 30 or 35 miles nearer to London than the two coal-fields last named, a boring has reached Coal Measures at a depth of 1,184 feet.

It has been shown that the coal-fields of the Continent extend to within a short distance from the English coasts; there is, therefore, a double foundation for the belief that the neighbourhood of London was, in the coal-making time, part of the great coal-making area.

The next point to consider is—What determined the preservation of some portions and the destruction of others of this widely-extended mass of coal-bearing strata? The solution is to be found in the character of the disturbances to which they since have been exposed, at different times but especially during the space of time between the close of the Carboniferous period and the beginning of the Triassic or New Red Sandstone period. *Then* were the Carboniferous rocks bent into folds, or, in the words of Sir A. Ramsay, "into a series of undulating anticlinal and synclinal curves."* That part was most exposed to denuding agencies which rose highest; the tendency was towards a levelling down; in fact, the anticlinal curves were actually shaved off before the Secondary period was far on. The result is that the upper beds (the Coal Measures) remain only in the synclinals or basins, while the Lower Carboniferous beds crop out where there was an anticlinal. If, then, we can determine in any way the run of the anticlinals affecting the strata that unconformably underlie our Secondary rocks, we may get to know where to expect the lower and where the higher of the Palæozoic beds.

Mr. Godwin-Austen attempted to do this for the south-east of England by connecting the line of strike† of the Carboniferous beds of the Boulonnais with that of the Valenciennes and the Belgian coal-fields on the east, and of the beds making the Mendip Hills (the southern boundary of the Bristol coal-field) on the west. From the plotting down of these directions on the map it is seen that they fit into one general curve which would run along some miles on the south of London and be the southern boundary of the "London Coal-field." I would here repeat that thus far Mr. Godwin-Austen had arrived in the year 1856, and the soundness of his method has since been generally recognised. The problem is, however, complicated by the fact that beds lower still than the Carboniferous limestone have been affected by the upheavals and exposed in the denudation, so that along any particular line (not coinciding with the "strike") any member of the Palæozoic beds may have been brought up, and in Secondary times exposed.

We can now with advantage turn to what has actually been found in this interval of twenty-five years to shake or verify Mr. Godwin-Austen's conclusions. Within this period certain most interesting borings have been made in the neighbourhood of London. With one exception they were undertaken on the old theory of the continuous extension of the Lower Greensand beneath the London basin, and with the expectation of that formation yielding a supply of good water; happily for geologists the warnings of the Kentish Town sinking were unheeded by the hydraulic engineers, and borehole after borehole has been made in the same—but as it has turned out vain—hope. After the Kentish Town boring, one was made at Crossness, below Woolwich, which gave somewhat similar and equally indefinite results; it reached, at 900 feet,

* An anticlinal is an upward bend of strata (saddle-shaped); a synclinal is a downward bend (trough-shaped).

† *Strike*, the direction at right angles to the dip of strata; it is the direction along which they would *stretch* if they cropped out on a level surface.

some red sandy stuff, that might by appearance belong either to the Old Red or the New Red Sandstone. In the year 1877 more positive information was obtained. In the corner between New Oxford Street and Tottenham Court Road stands Meux's Brewery, and for the use of that establishment a boring for water was made. At a depth of 1,000 feet the bottom of the Gault was reached, and the Lower Greensand entered on, but this last was different in lithogical character from the same formation at its outcrop, and, indeed, it could only be recognised by its fossils; not far beneath, at 1,060 feet, dark-coloured shale was met with, whose dip was clearly shown by the *cores* brought up in the boring tool to be about 40° in amount, and in this shale fossils were found which Mr. Etheridge at once recognised as belonging to the upper part of the Devonian formation—that formation which next underlies the Carboniferous. The *direction* of the dip of these beds could not then be determined, but it has since been inferred from facts observed elsewhere that it is towards the south. This was the first actual determination of the age of any of the old rocks beneath the Tertiary and Chalk area of England.

The next exploration was made at Turnford, near Cheshunt, twelve miles north of London; here again, after 940 feet of Tertiary and Secondary rocks, Upper Devonian was touched with the same fossils as at Meux's Brewery. At Ware, twenty miles due north of London, the New River Company made a borehole in which, at a depth of only 800 feet, the Palæozoic rocks were met with, but this time it was another of their divisions, namely, the *Upper Silurian*, that which underlies the Devonian. Details of these borings, especially of the Palæontology, were given by Mr. Etheridge in his Presidential address (1881) to the Geological Society. He states that the Upper Silurian fossils found at Ware include thirty-three species identical with those found in the Silurian rocks in Shropshire and Staffordshire, and prove a continuation of the rocks of that age from those counties to Herts. Now these Silurian beds were found to dip to the south-east at an angle of 40°. This accounts for the formation next above them being met with at Turnford, and it goes towards showing that the dip of the Palæozoic beds is at all events more from north to south than from south to north.

Thus evidence is accumulating that the floor of Palæozoic rocks beneath the Secondary rocks is at a depth of about 1,000 feet below the sea-level. With regard to the composition of the floor, the evidence at present points to the existence of Carboniferous rocks somewhere south of Oxford Street; the Lower Carboniferous might crop up against the Secondary rocks beneath the Thames in London, and a coal-field lie between South London and the line of the North Downs or Surrey Hills. I think that this conclusion or hypothesis embodies the latest information, but since Palæozoic rocks are often much disturbed, there may be variations of both dip and strike that would make these expectations wrong. Actual experience of what lies beneath that area will be waited for by geologists with the deepest interest.

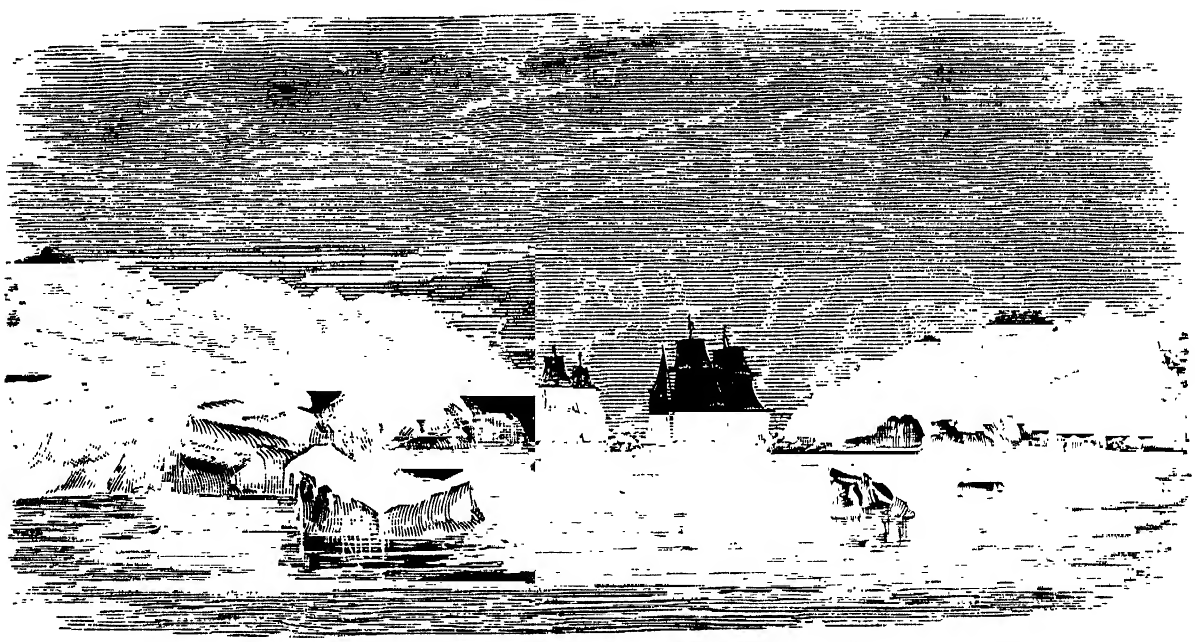
Finally, if the inference be right of the extension of the Warwickshire Coal Measures towards Daventry and Buckingham, this would be a separate area from the "London Coal-field," which, if it ever becomes an actuality, must result in immensely increasing the population of the metropolis.

AN ICEBERG.

By Dr. Robert Brown, F.R.G.S., etc.

THE voyager who for the first time sails for the far North is full of expectations regarding the sights to be seen in the "realms of ice and snow." He is bound, let us suppose, for Baffin's Bay, one of the main entrances to the Polar Basin. Bears and walrus, seals, and their elder brethren the Eskimo, all occupy some portion of his imagination; but, incontestably, the first place is reserved for the icebergs, which are so peculiarly the creations of the cold lands to which he is sailing. He has, it may be, rather confused notions regarding their nature, and is apt, like the newspaper chroniclers of whaling disasters, to consider them identical with the floating "fields" and "floes" which send so many stout ships to the bottom, though in reality the sea-ice, and not the land-ice, is to be discredited with the greater number of these mishaps. The visitor to the North must approach it with a mind remarkably open for fresh impressions, if he has not already formed some idea

of these wonderful mountains of ice. They form the staple background of every Arctic view. Their gigantic peaks and jagged precipices are familiar from a score of more or less imaginative engravings, until an iceberg—of the books—which was not at least a thousand feet in height, and failed to possess the accompaniment of a ship sailing in perilously close quarters to it, and a polar bear perched uncomfortably on the loftiest pinnacle, would be considered a work of art affording but a dull reflection of the original. To imaginations thus wrought up to superlative pitch, the first view of the first iceberg is singularly depressing. The ship is pitching about—say—in the cross-seas near the mouth of Davis Strait, preparatory to entering the smooth water of "the Arctic," when in the distance the eye catches sight of a lump of ice, looking, as it rises and falls into the trough of the sea, not unlike a hen-coop covered with snow, or a gigantic lump of foam tossed on the crest of a wave. If the day is sunless, the reflection of light which gives it that glistening appearance, so remarkable as the midnight sun glances among an array of these objects, is wanting to add dignity to the countour of what it is a rude dissipation of life's young dream to learn is an iceberg—though on a very small scale. It is simply a wave-worn straggler from the fleet which will soon be met sailing southward out of the Greenland fjords. The warm waters of the Atlantic will in the course of a few days be too much for it. The sun will be at work on it; it will get undermined by the wash of the breakers, until being top-heavy, it will speedily capsize. Then the war between the ice and the elements will begin afresh, until the once stately ice-mountain will become the "bergy bit" of the whaler, and finally disappear in the waters, only to arise again in the form of vapour, which the cold of the North will convert into snow, the parent of that "inlands ice" which, as we shall see, is the penultimate ancestor of the iceberg. As the true regions of cold are approached, the icebergs become more numerous and of larger dimensions, until as we pass the entrance of some of those great fjords, or inlets, which intersect the Greenland coast-line, they pour out in such numbers that the wary mariner is thankful for the continuous daylight and summer seas that enable him so easily to avoid these floating rocks. Here are several broken-up ones floating about in the Waigat, a narrow strait between the island of Disco and the mainland of Greenland, and in close vicinity to several fjords noted for the discharge of these "ice-mountains," as they have been very appropriately termed (Fig. 1). One aground inshore, and larger than the pieces figured, presents a dull white mass of untransparent ice, jagged on its summit, but on the whole not so closely resembling a Gothic cathedral as the pictures would have led us to suppose. Still, its shape is striking, while its size and general character lose nothing by being closely examined,



g. 1.—In the Waigat, North Greenland: Broken-up Bergs.

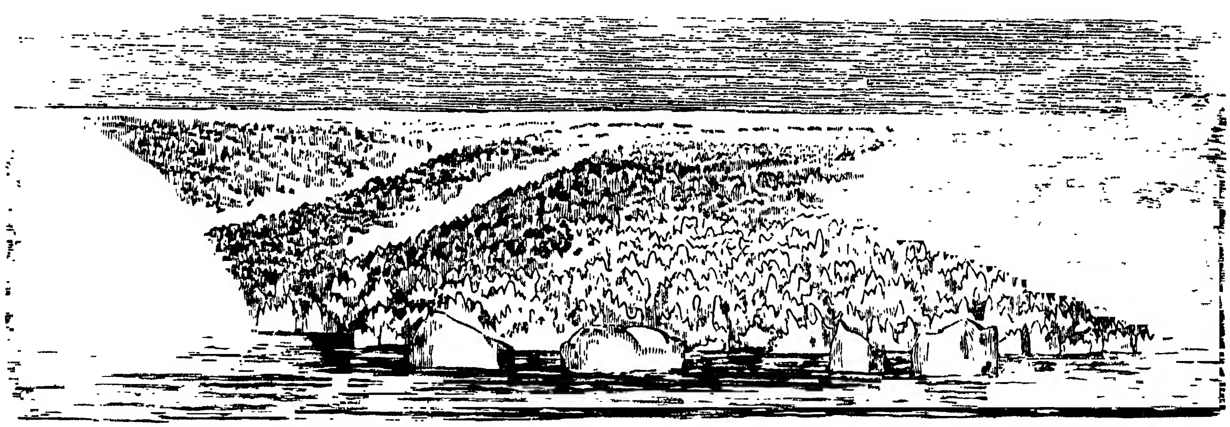
and the details ciphered out. Icebergs may sometimes be seen 150, 200, and even 400 feet in height; but the one before us is of more modest dimensions, and does not rise above the surface more than 100 feet. The colour of this "ice mast-high," unlike that described by the ancient mariner, is not as "green as emerald," but dull white. The sides are dripping with the little streams of water formed by the melting of the ice, and glistening in the rays of the sun; but a dull white is the prevailing colour of the mass. Its base is broader than its summit, and is here and there hollowed into little caverns by the action of the waves. The pinnacles seen in the pictures are not markedly present. Indeed, both the one we are examining and the numerous others in close vicinity are flattened on the summit, and if here and there worn into fantastic shapes by the weather, the tendency always is for it to resume a shape which may be roughly described as broader at the base than the apex: otherwise the berg would speedily capsize. Indeed, if we wait long enough, such a sight will be witnessed. On some of the bergs we see masses of earth, gravel, and stone, proving that they must have had recent connection with the land; for owing to the old bergs becoming undermined by the waves, they soon turn over, of course depositing, during that operation, their load on the bottom. An examination of the sides of the ice-mass also reveals to the eye some further peculiarities. The greater proportion of the ice is of a white colour, thoroughly permeated by very thin longitudinal, or lineal, air-bubbles, which lie parallel to each other; but throughout the white ice there are numerous slight fissure-like streaks, of an intensely blue and transparent ice, which, on being exposed to heat, before melting, Dr. Rink informs us, dissolve into large, angular grains. These blue fissures cross and intercross in the mass of the berg, and may possibly be water which has melted and become frozen again either on the surface of the berg or in its *crevasses*, or fissures, when it was a part of the glacier from which we shall presently see it is derived. But besides the blue ice, in some icebergs may be seen a kind of conglomerate, or, rather, what geologists would call a breccia, of ice-blocks of various sizes, the interstices between them being filled up with snow or crumbled ice. This conglomerate exists usually in fissures, though it is found also in layers, and even forms considerable masses of the larger bergs, combined with stones and earthy foreign substances. "Entire bergs," the late Governor of Greenland writes, "are also occasionally found composed of these kinds of ice; and from some ice-fjords, or inlets, which discharge bergs, scarcely anything issues but ice tinged more or less with blue, and intermixed with earthy matters." *

We find that the iceberg is not of salt-water origin, since the melted material of it is quite fresh. Indeed, by carrying a hose from the ship's tanks into the pools on the summit of the berg the seamen supply the vessel with drinking-water. This fact ought, however, not to be considered in itself a perfectly indisputable proof of the terrestrial origin of the iceberg, for the field, or floe-ice, floating past the ship, and which undoubtedly consists of the frozen surface of the sea, is likewise nearly fresh, and on the surface actually so, the tendency of freezing being to precipitate the saline particles, while the upper layers of the Arctic ice-fields are to a great extent simply the slush and frozen snow that have accumulated on the "bay-ice," or the first thin sheet which forms at the approach of winter. Nor would it necessarily follow that because rocks and earth are now and then found on the bergs they are of the earth's kindred. The chances are that on the surface of that floe past which we are sailing, and some pieces of which are almost undistinguishable from broken-up bergs, will be found gravel, earth, and other land *dêbris* which have fallen from the cliffs during the spring while yet the sea-ice was attached to the shore, or in the spring when the remnant of the winter's field remained attached to the shore in the shape of that narrow border known as an "ice-foot." Moreover, sea-ice sometimes freezes to the bottom, and when it becomes detached in the summer will carry up with it stones, &c., which have been embedded in its mass. No doubt, in the case of field-ice, these foreign materials are usually on the under surface; but a berg which gets aground will occasionally carry off with it a similar burden, and when in due course it capsizes, by becoming top-heavy, the *dêbris* which was originally in its base is borne along on its summit, the position of the burden of such an ice-raft giving not the slightest hint as to the source whence it was derived, or the manner in which it came to be placed in such a spot. However, the size of an ordinary iceberg suggests that it could neither have been the child of the sea nor of a river, provided there were rivers of any great size flowing into Davis Strait or Baffin's Bay. The one we are examining pro-

* Rink: "Danish Greenland: its People and Products," edited, with an Appendix, by Robert Brown, p. 358.

jects about 100 feet above the surface; but if we take a piece of the ice and allow it to float in a vessel of sea-water we shall find that for every foot which is above the surface there are about seven below it; that is, provided the ice is of the usual white character.

The next question is—Where do these bergs come from? The Atlantic voyager who comes into uncomfortable proximity to those which drift southward to the banks of Newfoundland, or even farther, has no opportunity of satisfactorily answering this question. Even the Arctic navigator, if he contents himself with simply skimming along the coast, will not arrive at a much more conclusive solution of the problem, as is proved by the absurd theories of their origin mooted by those who wrote about them no later than a century ago. The coast of Greenland is cut into from south to north by a number of more or less parallel inlets, which give that country roughly the appearance of two combs placed back to back, but with the teeth wide apart. These fjords lead to what is really the continental part of Greenland, just as the body of the hand might be described as its continental portion, and the spaces between the fingers the fjords. But when we begin to examine Greenland we find that the rocky peninsulæ between the fjords and the numerous mountainous islands lying off the coast are in fact the only real land in the country; in other words, that Greenland is a huge mass of glacier ice—or, at least, land covered with a great glacier—surrounded by the circlet of land which we see in sailing along the coast. Few Europeans* have caught a glimpse of this dismal waste, which, though perfectly well known to the old writers on Greenland, was not until comparatively recently understood, and even yet its nature is sometimes not quite grasped by the geologists who write so omnisciently on the Ice age in Europe. To approach the "inlands ice," as the Danes in Greenland style it, the easiest way would be to sail up one of these deep fjords, whose lofty walls and wild scenery form so attractive a feature of the barren region we have entered. It is probable that if we selected one out of which icebergs were sailing, we should discover it ending as in Fig. 2. The "inlands ice" pours from the interior in a short stream through a cleft between two islands; but if the water in the vicinity is shallow, and the slope by which the ice descends to the sea very gradual, it will not discharge itself in the shape of large masses. Comparatively small bergs are the most it gives birth to, and by means of these it relieves itself of the ice continually pouring from the interior, the white dismal stretch of which can be seen extending off towards the east. If we attempt to penetrate a deep ice-fjord we are soon repulsed by the imminent dangers of the voyage. A roll of the otherwise smooth lake-like water indicates some disturbance ahead, while at intervals the crash of ice and an explosion like the discharge of a park of artillery echoing and re-echoing among the lonely cliffs, and even scaring the cormorants, molliemokes, and looms, which cover the highest fells, warn us to proceed warily. There is a gentle breeze blowing from the land, and soon a long procession of icebergs comes sailing like a fleet of silver castles from the upper reaches of the fjord. To graze one of these is to insure the destruction of the vessel, to play the buffer between two of



2.—The Top of Omenak Fjord, at Innerit Ice-stream, North Greenland, showing the "Inlands Ice."†

* The writer is one of the only two Englishmen who have ever set foot on it. The other was his companion, Mr. Edward Whymper, so well known as an Alpine climber.

† After Rink: "Grönland Geographisk og Statistisk beskrevet," Vol. I., p. 11.

them would bring the voyage of the stoutest ship to a premature close. Even to fire a gun into the vicinity of an iceberg is dangerous, for the displacement of air caused will sometimes dislodge huge fragments of ice on the deck of the ship; while so well aware are the Eskimo of the peril this entails, that in paddling among icebergs, which they only do when compelled by necessity, they disturb the water as little as possible, and if they speak at all, communicate with each other in whispers. If, however, we manage to ascend the land overlooking the fjord, we can examine its nature and products much more fully. We shall be able to see that it ends in a lofty upright face of ice. This is the "sermiksoak," the great ice-wall of the Eskimo, and is in reality the seaward termination of the "inlands ice," which is every now and again relieving itself of the surplus ice, in the shape of the bergs which we met floating out to sea. To reach the "inlands ice" in this locality would be difficult and extremely dangerous. There is, however, a chance if we ascend one of the neighbouring fjords that we may be able to do so with comparative ease. We may sail up, say Pakitsok Fjord, and find it free of anything in the shape of glacier ice or ice-bergs. High cliffs, noisy with birds, are on both sides, and the land termination of the inlet is milky with the water of a clay-laden stream which flows into it. If we follow this stream through the mossy valley round the bluff which bars our path in a straight direction, we shall find that it flows from under the "inlands ice," a few miles to the east. Here the "inlands ice" appears in the form of a gentle slope which is slowly advancing towards the sea; but, contrary to what we see in Fig. 2, its way is for the present blocked by a steep slope in front, so that it must either first flow into the transverse valley between and then surmount the hill, when it can descend by a steep grade to the inlet; or it must wind through the narrow valley by which the glacier stream finds its way to the sea. This glacier stream we recognise as a familiar feature of the Alpine glaciers. It flows from under the ice, and may be regarded simply as the ice which has melted, or the surface-water which has found its way through the cracks and holes in the glacier, mingling with the mud derived from the grinding action of the glacier on the rocks over which it is ever slowly dragging. This mud we see shoaling up the fjord, and forming a fine laminated

Fig. 3.—Termination of a Greenland Fjord.

clay, identical with what we have seen among the ancient glacial deposits of Scotland;* and if we drink a glass of water from the milky stream we shall speedily detect it grating on our teeth. In an ice-fjord the stream may be seen welling up in front of the glacier's sea-face, in the form of a spring or whirlpool, surrounded in the summer by flocks of birds. In the winter it sometimes prevents the sea-ice from forming over such spots. surface will be coursed over by miniature rivers, which after running for a longer or shorter distance either discharge themselves over the seaward face of the glacier, or fall thundering through the great crevasses which scar the ice in every direction, or through the "moulins," or holes, which, as in the Alpine glaciers, are found here and there (Fig. 4). No sight nor sign of living thing appears on this "inlands ice" of Greenland, except here and there a

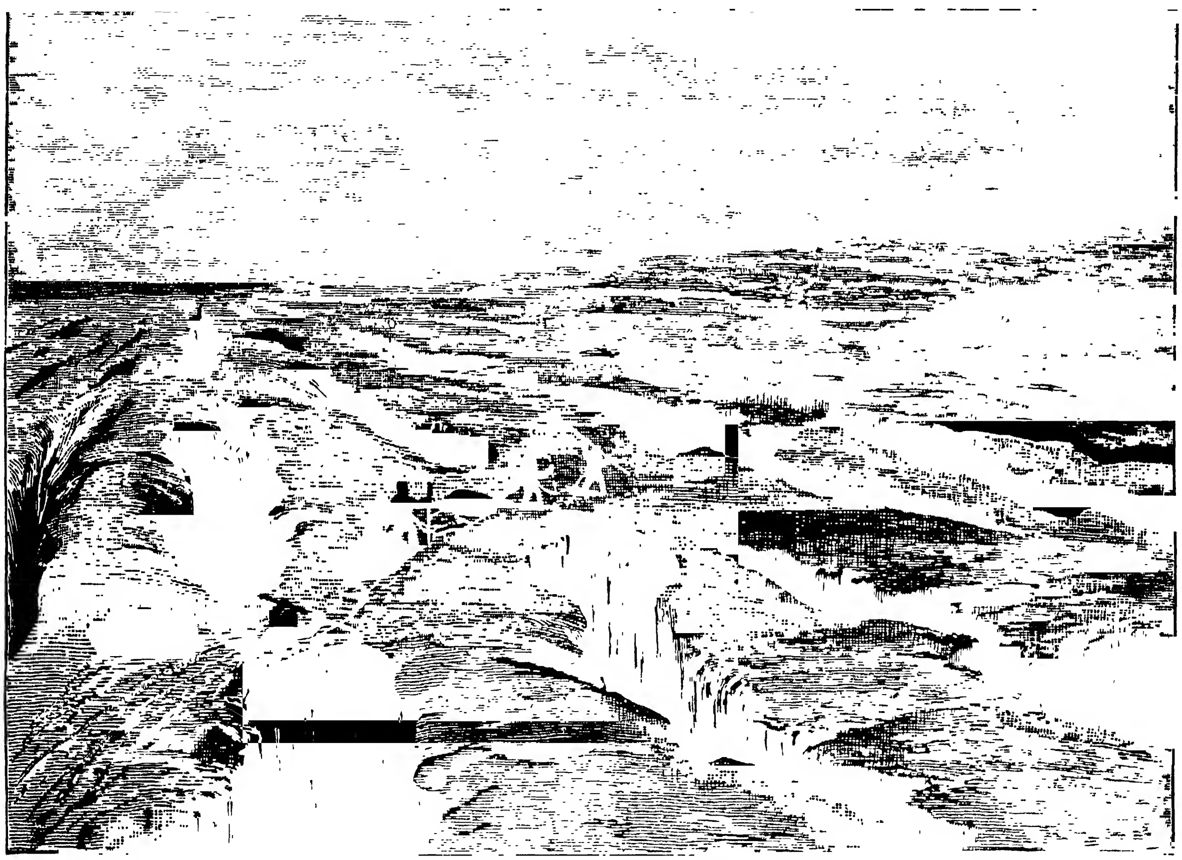


Fig. 4.—The "Inlands Ice," South Greenland.†

Clambering up this glacier slope we slowly ascend until we are on a level with the adjoining land, and have a full and uninterrupted view of this famous "inlands ice" of Greenland, which in various forms we have been made conscious of ever since we entered the Arctic regions. The ice is evidently sloping from east to west; but as far as the eye can reach, north, south, and east, nothing but ice can be seen. In every essential point the "inlands ice," though on a scale infinitely greater than anything we are acquainted with in Alpine countries, agrees with a mountain glacier. It is covered with the winter's snow, and studded with pools when this has melted. If the season is advanced the minute microscopic alga—a delicate plant belonging to the sea-weed order. The "moraines," so characteristic of Alpine glaciers, are wanting. These moraines, the reader who has already studied the pages‡ of this work need not be told, are simply the rocks, earth, and other *débris* which have fallen on the edges of the glacier as it ground its way through the mountain valley, or the stones which have become imbedded in its under surface, and then, after having melted out, are pushed before the glacier in its downward progress. The absence of these moraines proves incontestably that the "inlands

* "A Highland Glen:" "Science for All," Vol. I., pp. 37, 38.

† After Kornerup: "Meddelelser om Grönland," Vol. I. (1879), tav. II., p. 56.

‡ "Science for All," Vol. II., pp. 181, 267.

ice" in its course to the sea could not have come in contact with any great land mass, at all events, in the manner which ordinary glaciers do. However, when the "inlands ice" approaches the circlet of land which surrounds Greenland and forces its way through clefts in the marginal wall to the sea, it takes on the moraines, which are often seen on the surface of the icebergs floating out at sea. Strangely enough, however, in little hollows in the "inlands ice" is found a curious powder-like mineral, which Baron von Nordenskjöld has called Kryokonite, though what is its origin is not fully solved.

A still more inexplicable problem is—Where does the "inlands ice" come from? Our ideas of glaciers are so associated with mountains that we find it difficult to divest ourselves of the notion of the one being inseparable from the other. In reality height, except to afford a slope whence the glacier can slide, is immaterial; cold, to enable the snow of which it is composed to consolidate, is the essential point. That the highest point of the interior of Greenland is lofty, is shown by the fact that though the farthest distance to which the "inlands ice" has been explored is about one hundred and thirty miles towards the east, the elevation was then nearly 6,000 feet. Now at no place, and at almost no season, is Greenland—even at the sea level—not chilly enough for the formation of glaciers, while the interior, at the elevation of a few thousand feet, must be perpetually arctic and lofty enough, apart from the necessities of the latitude, for converting its "garnered snows of a thousand years" into true glacier ice. It is, therefore, in the highest degree probable, whatever might have been the original condition of Greenland—and we know from the remains of semi-tropical plants found in beds of very recent geological age that it was at one time blessed with a warm climate—that, with the exception of a point here and there projecting above the general mass, the whole of the original land surface is now overwhelmed with ice.* The few spots known to project above the ice are called by the Eskimo "nunataks." But at most they are small in circumference, and, as is the case with those recently explored a few miles from the coast of South Greenland, do not differ in any important particulars from the uncovered land in the same latitude. In reality, their presence confirms rather than weakens the theory just mooted. The ice in their vicinity is alone furnished with moraine, derived from coming into contact with them, for in all likelihood the earthy matters (p. 330) found incorporated with bergs are simply the mud and stones frozen into the under surface of the "inlands ice" on its long slow crawl to the sea. At all events it cannot be disputed that this "inlands ice" is moving towards the sea. Most probably the motion is towards both sides of the country, though we know so little about the east coast of Greenland that this can only be guessed at; but, from the greater abundance of icebergs on the western side, the chances are that the motion is much more rapid in that direction. When the "inlands ice" reaches the land margin—or "outskirts," to use the Dano-Greenland term for the uncovered portion of country—it naturally continues its downward course, and had the coast been an unbroken beach throughout, would show seaward one long ice-wall. This is not the case. It finds its outlet between the islands, or through the valleys which form the inland continuation of the fjords. If the cleft through which a portion of the "inlands ice" extends is broad, the "glacier," as it is sometimes called (though in reality the entire "inlands ice" is one immense *mer de glace*), is broad; if it is narrow, the glacier is narrow; if it is shallow, it reaches the sea in the manner shown in Fig. 2; and, finally, if the cleft through which it finds an outlet seaward is deep, the "inlands ice" reaches the head of the fjord in the form fitted for discharging its surplus in the

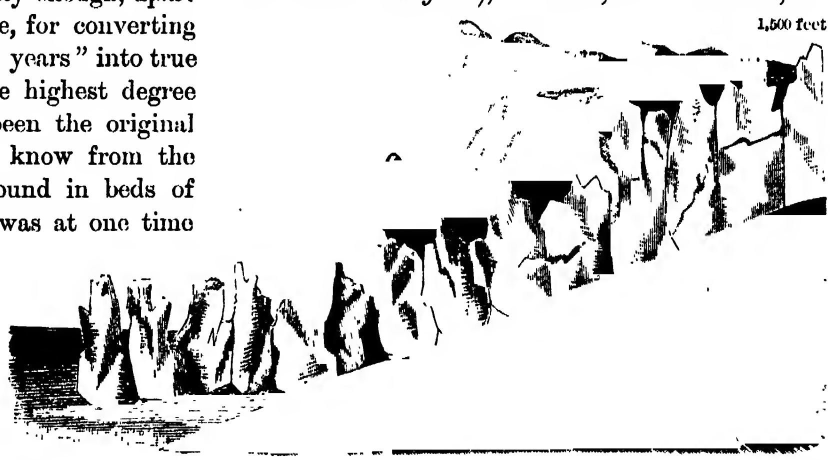


Fig. 5.—The "Inlands Ice" abutting on the Bottom of an Ice-Fjord, i.e., a Fjord in which real Icebergs are formed, and from whence they are discharged into Baffin's Bay.†

* In this necessarily brief sketch it is impossible to give more than the simplest facts, but in "Arctic Papers of the R. G. S.," pp. 1–70, I have described the physical structure of Greenland in more complete detail; and in an earlier paper—"Das Innere von Grönland" (Petermann's *Geographische Mittheilungen*, 1871, p. 378)—the general character of the interior.

† After Nordenskjöld: "Redogörelse för en Expedition till Grönland, år 1870" (Fig. 5).

form of large icebergs (Fig. 5). Now, it does not happen—as sometimes supposed—that when the "glacier" reaches the sea the iceberg tumbles off simply by the force of gravity. On the contrary, the glacier grinds along the bottom, and, if the fjord be shallow, may project into the water for a long distance. But in time the end will reach water so deep that it will get buoyed up. As it is pushed farther out by the pressure from behind, it will sway up and down, like a "sawyer" in an American river, until finally the end will be broken off and float away in the form of an iceberg, the size of which the crevasse has determined (Figs. 5 and 6).

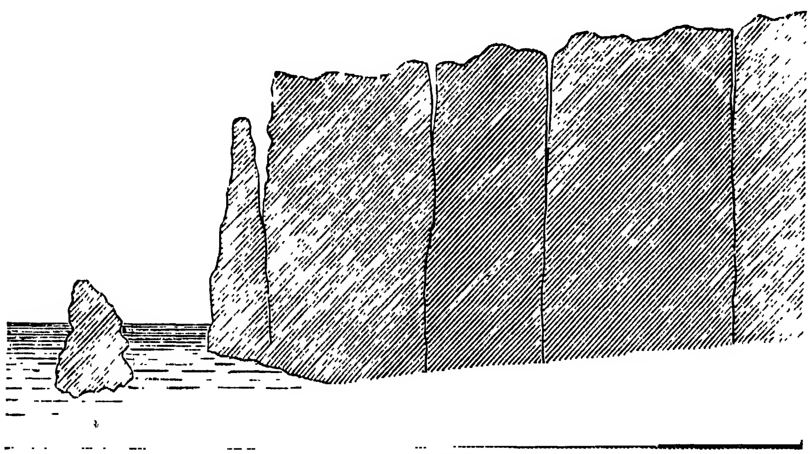


Fig. 6.—Diagram of the "Inlands Ice," extending into the Sea and terminating in a Steep Face; 100 ft. to 200 ft. high, from which Icebergs are "Calving." (*After Nordenskjöld.*)

But this operation is not accomplished quite so calmly as might be inferred from the few words we can devote to it. Mr. Helland, a Norwegian geologist, who visited Greenland eight years after the writer did, had an opportunity of witnessing the birth of a family of icebergs at Jakobshavn Fjord. "Without any previous indication"—I am quoting Dr. Rink's description of the scene—"a tremendous roaring noise was heard, while at the same time a white dust was seen to rise, and a large piece of the glacier was detached from its outer edge, which, after having rolled for some moments in the water, reared its edge in the air; but almost instantly the pinnacled top of this edge burst asunder and crumbled while falling. The calving having thus commenced, it was instantly followed by a much larger piece being detached, and issuing from the middle part of the glacier at the rate of one metre per second. But the extensive *bouleversements* which now ensued made it impossible to discern the number and size of the large bergs which were formed out of this portion of the glacier, because clouds of dust now arose in different places, and the floating bergs in the vicinity were also put in motion, rolling and calving. It was more than half an hour before the whole scene again was calm, and the thundering noise which had accompanied the disturbance had subsided. It is also worth noticing that the waters of Tivsarigsok, the small creek of the original fjord, separated from it by the glacier, were considerably affected, and the winter ice that covered it was seen to rise and fall violently."

We have taken the continental "inlands ice" of Greenland as the type of that by which bergs are discharged. In Disco and other islands, as well as in Spitzbergen, there are also "inlands ices" on a smaller scale, and, in addition, the mountains of the land margin of Greenland, as at Omenak, contain local glaciers identical in their structure with those of Alpine countries, except that while the latter never, save in Norway or on the north-west coast of America, approach the sea, the former cannot, owing to the character of the country and its climate, ever be far removed from the sea-level. Icebergs are thus products of the land, and though some of the great glaciers of Alaska (Muir's *e.g.*) actually reach the sea and discharge icebergs, they are, from their very nature, practically confined to the extreme north. It does, indeed, sometimes happen that icebergs drift far south; stragglers have been recorded as sailing in daily diminishing grandeur in the parallel of Spain, and there is even a case often quoted of one having been met with on the 18th of June, 1842, in latitude 38° 40′ north, measuring 100 feet in height and 170 feet in breadth. These children of the Frozen Lands are, however, as far out of their accustomed range as the Eskimo whose kayak is traditioned to have been captured not far from Orkney, and though the current habitually carries bergs to the banks of Newfoundland, and if the wind blows fair even farther, the student who hopes to see them in perfection, and to study their strange birth and character, must take up his abode by the side of a fjord like that of Jakobshavn, Sermelik, or Kangerdlursoak, in Greenland, where there is never wanting what John Davis described as "much store of ice and snow."

HOW AN ANIMAL WALKS.

By William Ackroyd, F.I.C.

THE walk of a man, or the trot of a horse, seems at first sight such a simple act as to admit of little scientific discussion. In reality, there are many points relating to the act which form a theme for hot debate among both physiologists and physicists, and those whose interest in the subject is of a less scientific character. We have known one set of men in a company maintain that when a horse is walking it advances both legs on one side together, and then follows with the legs on the other side; others of a different opinion have said that the right fore and the left hind legs advance together, and then the left fore and right hind legs. As it was not much use trying to settle the question with words, it has usually been resolved to resort to the street, to narrowly watch a few horses as they were slowly passing, when it has appeared so difficult and puzzling to follow the movements of all four legs together that each one has remained of the opinion that he held at first. It is a matter, however, in which both parties could not be right, and one or other was certainly wrong. We therefore propose to inquire into the problems of walking, and of the next stage of locomotion into which it imperceptibly merges, namely, running. To commence with one of the simplest cases, we may take that of a biped like man; for after learning what it is possible to know about the walk of a biped, it will be an easy step then to take into consideration the case of a quadruped.

One of the most remarkable things about a man's walk is the *diagonal* movement which characterises it. The reader may imagine the hands and feet to form the four corners of a parallelogram, and the diagonal limbs are of course the right arm and left leg, and the left arm and right leg. By "diagonal movement" we therefore intend to convey the fact that the diagonal limbs, during locomotion, always swing in the same direction. A soldier on parade keeps his arms motionless by his sides, and on no account must they be allowed to vibrate. This is not what he would naturally do if left to himself. Watch any one person out of the hundreds walking along the streets, and it will be seen that he invariably swings his arms as he goes along, perhaps to an extreme degree if he be a rustic, and less so if town-bred. The arms swing by the body like a couple of pendula, and with a speed which entirely depends upon the rate at which he may be walking. The athlete, anxious to complete the given number of "laps" in a mile or couple of miles and outstrip his competitors, swings his arms to and fro with a quickness which corresponds with the motion of his swift feet; the business man also swings his arms with a motion which, if not so quick, exactly times with the motion of his legs; and even the idle man about town, lounging along some fashionable quarter, unconsciously gives a slow motion to his arms which corresponds to his tardy legs. Now, if the motion be even carelessly observed, it will be found that the right arm swings forward at the same time as the left leg; and when the right leg is advancing, it is the left arm which accompanies it. This is the natural gait, and, to convince oneself that it is so, it is only requisite to get a friend to walk across the room in the opposite fashion—*i.e.*, to swing the right arm forward when stepping out with the right leg, and then, in the same manner, when bringing forward the left leg, to accompany it with the left arm. Such a gait is both unnatural and uncomfortable to the person who tries it, and also ludicrous to the observer who watches a first attempt of the kind.

The diagonal movement of the limbs is therefore the natural method adopted by man when walking, and it is the first and most apparent fact that one ascertains in studying human locomotion.

When a man is standing still, the essential condition of stability is the same, of course, as that of every other body—viz., that the vertical line falling from his centre of gravity shall fall within the basis of support; but in the act of walking the centre of gravity is pushed forward, and the continued act of pushing it forward with one leg, and then swinging this leg into a new position, while the body, so to speak, rolls over the leg whose foot is in contact with the floor, constitutes walking. Weber has shown that the advance of the hinder leg is not in itself a muscular action under ordinary circumstances, as it consists only of swinging it forward under the influence of gravity, the leg being for the time to all intents and purposes a pendulum. A long pendulum vibrates at a much slower rate than a short one; it therefore follows that if two persons are walking side by side with their natural step, the one with

the shorter legs will take a great number more steps than his companion with long legs in covering a given distance, and to keep in step, either the long man must take shorter steps than he has been accustomed to, or the short man longer ones. As we have already seen, the arms accompany the movements of the legs, and an athlete when walking fast or running usually bends his arms at the elbows. The reason is plain. It would evidently be a difficult matter for him to swing the extended arms, in quick walking and running, so as to keep time with the quickly-moving legs. He therefore, by bending his arms, makes them into shorter pendula, and it is now a matter of ease for him to swing them alternately forward as fast as his lower limbs. Increased speed is also attained in walking by lowering the centre of gravity of the trunk, by longer steps, by bending the limbs more, and by allowing the supporting limb to remain a shorter time on the ground. It often happens that, in reducing the time the supporting limb remains on the ground to a minimum, a competitor in a walking match is disqualified, as he breaks out into a run. Running is distinguished from walking in that the hinder leg is raised before the advancing leg reaches the ground. The exact nature of a man's movements when walking will be apparent from a few minutes' consideration of Fig. 1. The centre of gravity of the body is at G, and a vertical line dropped from this point to the floor falls within the area covered by the foot at J. Under such circumstances the body would be at a standstill; but the extension of the other leg gives a push to the body at G in the direction G F, so that we may regard the weight of the body, or the centre of gravity at G, as being acted upon by two forces—(1) the pull of gravity, and (2) the push of the extending leg, G J′. This latter force may be resolved by an elementary principle in mechanics into two forces, represented in magnitude and direction by the lines G V and G H. The latter force is of course the one which tends to carry the body forwards, and the former is the one which produces the up-and-down motion of the body in walking, and is opposed to the pull of gravity. The top of the head consequently in walking describes a wavy line, which is a combination of the up-and-down and onward movements.

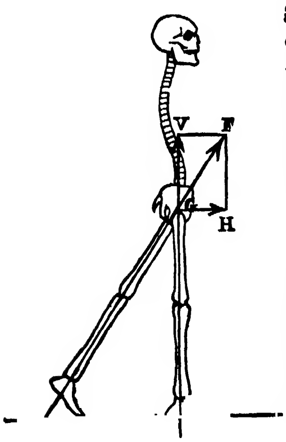


Fig. 1.—Forces at Work in Walking. (*After Weber.*)

In early times a certain significance was generally attached to certain numbers. Seven had a prominent position in this respect, as was painfully evident to the King of Egypt, whose dream related to the *seven* years of plenty and the *seven* years of dearth; and to Naaman, the Syrian leper, who was told to wash *seven* times in the Jordan. Then there were the *seven* wise men, the *seven* wonders of the world, and the *seven* champions of Christendom. One attaches very little importance now to a number in a mystical sense, but the very next number after seven—*i.e.*, eight—has of late years become one of importance in science, not so much because of the number itself, as of the form by which we represent it; for it will have been noticed that the figure of eight is a most important one in nature by those readers who have studied the physics in this work. It is one of the figures described when the vibrations of a couple of pendula swinging at right angles are combined; it is the luminous figure produced by Lissajou's method when two tuning-forks, an octave apart, are made to vibrate;* and it is the figure described by a wing in motion when the flying animal is artificially fixed. We here refer to it because of its importance in animal locomotion. According to Pettigrew, who was the first to point out the figure-of-eight movement in animal locomotion, there is a figure-of-eight track produced by the extremities both in walking and running. Thus *r* (Fig. 2) may represent the track traced out by the right leg when advancing, and *s* the path produced similarly by the left arm swinging along with it. At the very next step the curve *t* is produced by the advancing left leg, and the curve *u* by the right arm. By the intersection of these sinuous lines, we have a series of ellipses formed, any adjacent two of which give us the noted figure of eight.

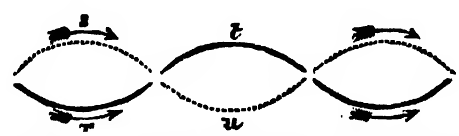


Fig. 2.—Figure of-eight Track, produced by the Alternating of the Extremities in Man in Walking and Running. (*After Pettigrew.*)

All the three kinds of levers are employed in the animal frame during locomotion—viz., the lever like the crowbar, where the weight to be lifted is at one end, the rest, or fulcrum, in

* "Science for All," Vol. III., pp. 97, 98.

between, and the power at the other end; the lever like the wheel-barrow, where the fulcrum (wheel) is at one end—at the point where the wheel is in contact with the ground—the weight in the middle, and the power at the other end, or handles; and the lever where the weight is at one end, the power applied at the middle, and the fulcrum at the other end, as in a pair of sugar-tongs. The way in which the organic levers act is well illustrated by the movements of the human foot. Thus, in the foot, when the toes are tapped on the ground (Fig. 3), we have an illustration of the first kind of lever; the ankle-joint being the fulcrum, the muscular power being applied at the back of the heel, and the weight being the fore part of the foot.

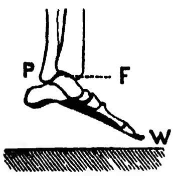


Fig. 3.—The Foot as a Lever of the First Kind.

When the body is raised in the act of standing on tip-toe (Fig. 4), the fulcrum is the ground, the power is applied by the muscles of the calf to the heel, and the weight to be lifted is that portion of the weight of the body which is borne by the ankle-joint; and here we have an example of the second kind of lever. And the same parts may also represent a lever of the third kind when one moves a weight resting on the toes up and down; for here (Fig. 5) the ankle-joint is the fulcrum, and the power is furnished by the extensor muscles at the front of the leg.

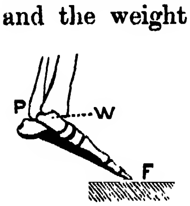


Fig. 4.—The Foot as a Lever of the Second Kind.

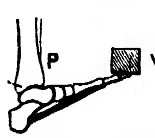


Fig. 5.—The Foot as a Lever of the Third Kind.

Of course, movements of this nature are employed to a greater or lesser degree in every act of locomotion, only the power is supplied by the contraction of several muscles all associated together. It will be perceived that it is the solid framework, or bone, which furnishes the arms of the levers, and that the fulcra may be either joints or the solid ground. Joints act the part of fulcra in many movements of the body. Thus, when a gymnast is slowly raising one of his legs in the act of advancing it in peculiar gymnastic style, which is different from the pendulous swing in ordinary walking, the fulcrum is the hip-joint, and the weight the mass of the leg; but when the foot of this same leg has come down to the floor, the fulcrum is now the ground, and the weight to be moved, or kept moving, is the mass of the body. Hence we have two kinds of fulcra to consider—joints, and the surface which is being travelled over; action on the former producing motion in the animal frame, and action on the latter producing a motion of translation, or locomotion. Assuming that the surface travelled over, or earth, be flat, it is of importance that the foot applied to it be small, so that there may be a minimum amount of resistance; just as in the chemical balance, where a knife-edge rests on an agate surface for a fulcrum.

Of other bipeds, birds, as a general rule, are not adapted for either walking or running well. A noted exception, however, is the order of birds which was formerly known as *Cursores*, and now named *Struthiones*. The long and powerful legs and small feet of the cassowary and ostrich are remarkably well adapted for running; especially is this the case with the latter. The foot of the ostrich has only two toes, and the sole is flat and well adapted for locomotion on plane surfaces. The prodigious strength of its legs also adds greatly to its running capabilities. Of its strength of limb, some idea can be formed from the fact that with a single stroke it has been known to break the thigh-bone of a man, and also to lay dead at its feet dogs that have been employed in hunting it. At the extremities of its toes it has powerful, short nails, the tips of which project below to protect the toes, and they also give an elasticity to the foot when leaving the ground. To these advantages we have likewise to add the fact that its short wings, which it uses when running, are excellent accessories, and materially increase its speed. When about to run, it stretches out its neck, and inclines its body forward; the legs are then moved alternately with great rapidity. The motion of these two legs is of course comparable with the motion of a man's legs; for the trunk is momentarily supported by an extended leg, which touches the ground, while the other leg swings forward in pendulum fashion. The leg which is touching the ground acts the part of a lever of the third kind, the ground being the fulcrum, and the weight of the body, concentrated, so to speak, at the centre of gravity, being the mass to be moved forward.

In the locomotion of a quadruped like the horse, for example, the first thing that we have to call attention to is the diagonal motion of its limbs. It is a hopeless task, in nine cases out of ten, for a person to make out this diagonal motion who is unaccustomed to observing intently the walk of a horse. It may be seen, however, very easily when cattle are grazing, because then the motion of the limbs is so slow that one can

leisurely follow their steps without getting perplexed; and again it is observed with ease in a horse when trotting, because it moves its diagonal limbs both together, and they reach the ground nearly, if not exactly, at the same moment of time. The difficulty which is experienced in the case of a horse walking at its ordinary speed—*i.e.*, neither fast nor slow—arises from the fact of its diagonal limbs not exactly swinging together like the diagonal limbs of a trotting horse or walking man, but having the hind limb of the diagonal pair slightly lagging behind the other. If we number its feet 1, 2, 3, and 4, as in Fig. 6, and suppose

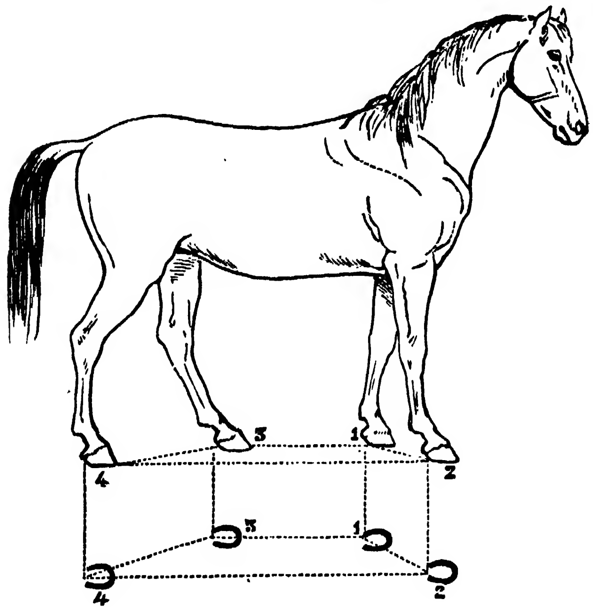


Fig. 6.—To Illustrate the Step of the Horse.

that it is standing with them as there represented, we should find that upon commencing to walk, if it stepped out with 1 first, this would be followed by 4; then 2 would advance, and be followed by 3 slightly behind. It is pretty evident, if one listens to a horse as it is walking along a stone-paved street without watching its feet, that never more than one foot is put down at a time, and the order in which they are put down, referring once more to Fig. 6, is 1, 4, 2, 3.

The walk of a quadruped like the horse may be compared to the walk of a couple of bipeds, with a common body between them, and from the order of the movements of the legs it follows that the body in advancing has a serpent-like motion given to it. A twist is given to the fore part of the body when the fore legs are separated, and a twist is given to the hind portion of the body in the opposite direction when the hind feet are separated. Pettigrew points out that this may be well observed in a cat when walking, if one looks at it from above. A continuous wave of movement is then observed travelling along its spine from before backwards, which closely resembles the crawling of the serpent and the swimming of the eel.

There are few more common objects in our land than the horse, so that many of the foregoing and following remarks concerning its locomotion readily admit of verification. The paces of the horse are divided into the walk, trot, amble, and gallop. In the walk and trot there is the diagonal movement we have already spoken of. In the amble, which is not so natural a step for the horse as the others, the feet on the right side move together to form one step, and the feet on the left side move together to form the second step—like the camel when pressed into a gentle pace, or the giraffe when running. One has generally the impression that the gallop consists of a series of bounds—an idea which is certainly strengthened by the rise and fall the rider is subjected to; but it has been maintained that if the gallop consisted of a repetition of bounds the horse could not keep it up so long as it does. Gamgee has made careful measurements of the walk, trot, and gallop of a horse, which will be readily understood. Fig. 7, A one might regard as the impressions of the hoofs of a horse when walking. The distance between each impression is put down in inches, so that the length of step of hoof 1 in walking is evidently five feet four and three-quarter inches. The diagram represents a rapid walk, so that after the first foot has taken its stride of over five feet into a new position, the third foot steps eleven inches in front of the vacated position; in a slow walk it may be several inches behind. It is easy to see, therefore, that there will be a pace where the third foot exactly replaces the first, and if the movements of the feet be not timed properly, it sometimes happens that the hind foot knocks off the shoe of the fore foot.

In the trot, it will be observed that the third foot alights farther still in front of the first; in the particular example represented in Fig. 7, B, the third foot being nineteen inches in advance of the first. The steps are also longer, the second position of the first foot being ten feet one inch away from its first place. An inspection of the hoof-marks made in the gallop (Fig. 7, C) shows that the distance between two consecutive positions of the fore foot is much greater than in either the walk or the trot, being in this particular instance eighteen feet

five inches. Of course the length of the step in different horses varies as much as it does in different men, and the figures quoted here refer to a particular horse whose movements were studied by Gamgee. This much is pretty apparent from the diagrams, that the length of stride depends on the speed acquired, the momentum of the moving body carrying the limbs forward with it. The

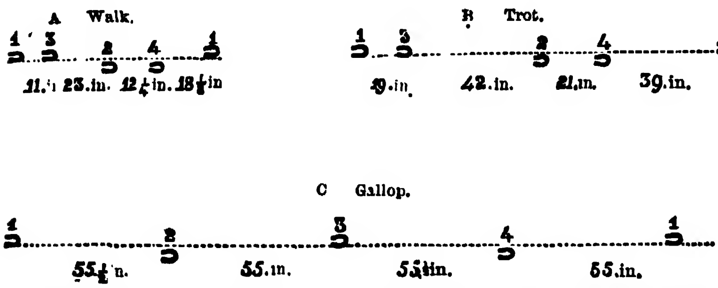


Fig. 7.—The Length of Step in the various Paces of a Horse. (*After Gamgee.*)

same remarks of course apply to man, whose stride is much longer in running than in ordinary walking.

The diagonal movement in the quadruped, as seen in the walk and trot of a horse, seems to be the most natural, and the amble is only produced by the art of the trainer. There is not that continuity of motion in the amble that there is in the diagonal movement, and on this ground alone one could understand a horse's preference for it. Perhaps it would not be difficult to assign other reasons besides for the diagonal movement. Thus it appears not improbable that the line joining two diagonal legs is nearer to the vertical line dropped from a horse's centre of gravity than a similar line joining two side legs would be; so that if the animal had to balance itself on two legs, it would be easier to do it on 2 and 3 (Fig. 6) than on 1 and 3. A practical proof is generally refreshing to the mind, and one is easily adduced in the present instance, if the reader will follow our instructions. Revert once more to the primitive mode of progression that you in all probability practised in your babyhood. Go down on all-fours. You will find that you are able to balance the body better on two diagonal limbs—say, for example, the right hand and left foot—than on two side limbs like the right hand and right foot. In the latter case there is a greater tendency to fall over on one side. When, therefore, you proceed to imitate the walk or trot of a quadruped, the diagonal step appears to be the most easy and natural. One can get along better with it than by advancing with the two limbs on one side, and then the two limbs on the other, which gives rise to a waddling gait. It appears, therefore, not improbable that the diagonally opposite feet of a quadruped are better placed for supporting readily the body of a horse than two side feet; consequently they are so employed while the remaining two diagonal feet are used for advancing to new positions, to become in their turn efficient supports of the body.

The most perfect form of motion, if it could have been used conveniently in the animal world, would have been that of a rolling sphere. For example, what other form of body will go so far or so easily along a plane surface as a rolling cricket-ball? It has but one point in contact with the plane it rests on, and the vertical line let fall from its centre of gravity falls within that point. But perfect rotation in the animal frame is out of the question, as by it vessels would be ruptured and all continuity destroyed between the rotating organs and the parts they supported. It is, therefore, impossible to conceive of anything which would better subserve the purposes of animal locomotion than the admirably constituted limbs, with their small extremities, which project from the body.

The feet of animals, as a rule, are small and compact, and well suited for the ground they have to walk on. One could think of nothing better fitted for animals like the horse, cow, sheep, and pig, in their natural state, than the horny feet they possess, although it has been found necessary, of course, in the case of the first-mentioned animal, to fortify its hoof with an iron shoe, because of the peculiar nature of the roads it has constantly to travel in towns and cities, and of the pressure it has to apply to the rigid ground in drawing large weights. That peculiar power of adaptation to circumstances, too, which one finds so universally in nature is likewise well shown in the modification the extremities have undergone where the wants and habits of the animal rendered it necessary. The partially webbed foot of the otter fits it alike for swimming and walking; the large yielding foot of the camel suits it for travelling on desert sands with ease where the hard-hoofed horse would soon be exhausted; the velvety padded feet of the lion and tiger are exceedingly suitable for that stealthy tread which characterises the cat family when stealing on their prey; and wherever we look, all throughout nature, we find that the feet are adapted to the animals' surroundings. The swiftest are those which, like the gazelle, possess the smallest feet; for here, as Pettigrew well points out, a

double purpose is subserved by their small feet, "the limited area presented to the ground affording the animal sufficient support and leverage, and enabling it to disentangle its feet with the utmost facility; it being a condition in rapid terrestrial progression that the points presented to the earth be few in number and limited in extent, as this approximates the feet of animals most closely to the wheel in mechanics, where the surface in contact with the plane of progression is reduced to a minimum." Hence, if we compare a couple of families of one order of animals, say the carnivores, or flesh-eaters, we find that the fleetest are those like the dog and the cat, with feet comprised only of the toes which they walk on, and that the slowest are the bears, who are remarkable for their heavy gait, and whose feet are big, and planted flatly on the ground. The feet of the ostrich, also, as we have already seen, are reduced to a minimum, so that when this bird is running it can outstrip even the fleetest horses, the hunters being only able to capture it by the stratagem of running it backwards and forwards across the plain until it is exhausted.

So far we have been dealing with the more apparent aspects of the problem of animal locomotion. It is easy enough to see the antics of a wooden figure, to note the manner in which it moves its legs and arms; but we cannot see the strings by means of which the marionette is moved, and we become at once curious to know how the thing is done. Within so small a compass as the cranium, or skull-case, all orders are conceived and set in action, so that if the horse, whose gait you have been studying, takes it into its head to kick you, its leg is communicated with from the brain, and extended to its fullest extent by a mechanism far more wonderful than any ever employed in a marionette show. Some idea of how this is managed in the animal frame has been given already in the paper on "Nerves or No Nerves" (Vol. I., p. 174). The kick, however, given in this case differs from the ordinary walk in this—that the horse might walk for miles along a road without once giving a thought as to how it was putting down its legs or the direction it was taking; but when it gave the kick it was impelled to do so by some cause, and for the time being its equine mind was directed entirely to the act of kicking, both as regards direction and extent. In other words, the action was a conscious one. Now, when any particular action is often repeated, one can at length do it with but little, if any, thought, and then the action becomes an unconscious one. Walking is an unconscious action with a boy or man of normal health; but it requires no proof that when they were babies the hesitating and faltering step which was taken in the first attempt at walking was an uncomfortably conscious one, and only by prolonged repetition did it become an unconscious act. The act of walking, therefore, differs from a thousand other acts, in that it is an unconscious act.

The brain is a most wonderful and elaborately constructed organ, which regulates the movements of most of the other parts of the body, very much as a general and his staff regulate the movements of an army. Each particular portion of it would appear to have its special command; so that if this portion becomes diseased, the organs which it controls are no longer capable of well-ordered movements; or if it be excited, these self-same organs may be made to execute their special movements. In other words, it has been shown by the labours of many experimenters that there are in the brain certain centres of what is termed motor activity—*i.e.*, when these particular parts of the brain are affected, certain muscular acts are either prevented or produced. The experiments of Ferrier on this subject are of particular interest. He found that upon applying the terminals of an induction coil

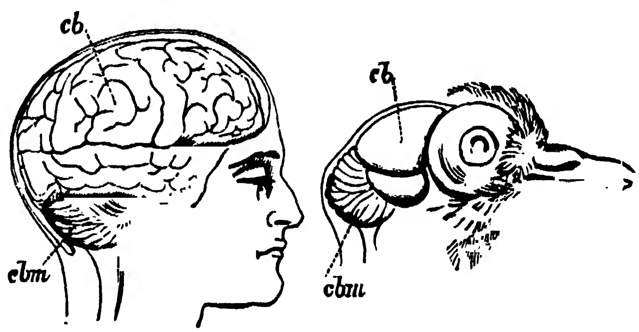


Fig. 8.—Brain of Man and of Pigeon. *cb*, Cerebrum; *cbm.*, Cerebellum.

to particular parts of the brain he could call forth certain actions, and he was thus enabled to make a rabbit munch, a cat move its foot and leg as if seizing a mouse, and a dog wag its tail from side to side. From the precise locality in which the brain excitement was produced he was able to predict the nature of the motion which would be called forth. These observations apply to what is termed the *cerebrum*, or large brain; for it will be understood that the brain is divided roughly into the *cerebrum* and the *cerebellum*, or little brain, which is placed at the back of the head (Fig. 8). A curious fact with

regard to this cerebellum was discovered by Ferrier. It was found to have control over the movements ot the eye-balls, regulating their rolling movements from side to side, and also that movement of the eyes which, when the head is swayed from side to side, keeps the image of an object on the same areas of the retinæ. Now, this is a very important fact, as one can well understand that a derangement of this portion of the brain would entail most serious consequences to one's power of walking. The following considerations will make this quite plain.

Suppose that, as you are standing in the street, from some faulty control of the eyes, images of external objects are cast upon areas of the retinæ which lead you to suppose that these objects occupy positions other than those they really do occupy; that the ground before you is higher or lower than it really is, that the lamp-posts, walls, and houses are placed differently from what they really are. What would be the result? In stepping on to the imaginary high ground, you would go down with the uncomfortable jerk that one experiences in stepping unexpectedly into a pit-fall; in avoiding the imaginary lamp-post you would very probably collide against the real one; you would be, in short, in the painful position of being thought to be hopelessly drunk. It appears not improbable that something like this happens when the cerebellum of an animal is destroyed; for it can no longer balance its movements, and steady walking is therefore impossible. The experiment which perhaps demonstrates this fact more than any other is the cruel one which was first performed by the French philosopher, Flourens. He removed the cerebellum of a pigeon (Fig. 8) in successive slices, thereby showing that there was a progressive effect upon locomotive actions. On taking away the upper layer of the cerebellum, the pigeon exhibited weakness and hesitation of gait; by the time the middle of the organ was reached it staggered, and assisted its walk by flapping its wings. At a further stage in the process it could no longer preserve its steadiness without the assistance of wings and tail, and the slightest touch overturned it. Finally, when the whole cerebellum was removed, it could not support itself even with the aid of its wings and tail; the sight and hearing being, however, quite perfect. From these experiments, which have been often repeated and as often found correct, it would appear that the cerebellum plays the all-important part in animal locomotion of co-ordinating the movements of the eye-balls and of the muscles generally. When, therefore, an animal is walking or running, the order and nature of the movements of its legs are determined by the cerebellum in some mysterious fashion, so that its gait may be correct in every respect.

But the animal mechanism concerned in locomotion is even more wonderful still; for it is an apparatus far more efficient than any human device for the utilisation of energy. In the best-constructed steam-engine only from eight to ten per cent. of the available energy is utilised, but in the human body as much as twenty-five per cent. may be turned into mechanical work.

We have taken but a cursory view of the subject of animal locomotion, but that has been sufficient to show us that the means adopted in nature for progression on land are simply inimitable. The flight of a bird and the swimming of a fish have been copied with some degree of success, but the god-like walk of a man never. Fabulous tales, somewhat vague in their details, come to us out of the mists of antiquity, attributing to Dædalus the credit of having constructed statues which walked; and we are told by Aristotle of a wooden Venus which moved about when quicksilver was poured into its interior. But even if we admit, what is very improbable, that these statues were worked to some extent by hidden internal mechanism, they could never subserve any other purpose than that of imposing on the credulity of the ignorant, or amusing those who could afford to pay for it. It would be a much easier matter to imitate the walk of a four-legged beast, because here there would not be so much difficulty in keeping the centre of gravity within the basis of support. Something of this kind appears to have been devised by M. Camus for the amusement of Louis XIV. when a child. A small coach was drawn by two automaton horses. Within the coach there was the figure of a lady, and a footman and page behind. At the smack of the coachman's whip the horses instantly set off, moving their legs in a natural manner and drawing the coach after them. Such devices are not more wonderful than the automata the reader may have often seen which have been set in motion by clock-work. But how immeasurably all these contrivances fall below the lowliest organism in wonder and utility of design!

A CLOD OF EARTH.

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THAT the soil under our feet is a soft, more or less loose, superficial layer of earthy matter requires but the briefest examination to prove; that in most cases it is intermixed with decaying substances, and resting upon the solid rocks beneath, from which, by processes of decay, it has been almost entirely derived, can be shown by a comparison of the nearest underlying formation. Sometimes this layer is very thin, forming merely the scantiest covering, and affording sustenance to only the very simplest forms of vegetable life, while at other places it may occur as a deep deposit of rich earth, able to support even successive crops of highly-developed plants in absolute luxury. Between these two extremes we have, of course, all sorts of gradations respecting depth; but in most soils of any considerable deepness of earth there exist a clearly-defined upper and under stratum, differing mainly from one another in the state of sub-division of their particles. The under, known as the subsoil, is stiff, plastic, and heavy, and passes gradually into the substance of the rock beneath, whose upper surface presents a broken-up appearance, due to the slow decomposition and consequent crumbling away of its substance.

Soils, however, are not always formed directly from the rocks above which they are found, as in many cases the materials have been carried and deposited there through the agency of water. Such transported soils, as they are called, may therefore differ very widely from the underlying rock, both in general character and chemical composition.

Among themselves, soils differ very much in their distinctive properties; in one district we have heavy clays, in other places light sands or marls, while in another part of the country soft, fibrous peat is the occurring soil.

Sands, clays, and marls are all disintegration products, derived from the gradual decay of various solid rocks. These rocks may have been either primitive crystalline rocks, like granite and syenite, or volcanic, as lava and whinstone; while sedimentary or aqueous rocks are often disintegrated to produce materials for the formation of soils. Air, water, and frost are powerful agents in this work of rock destruction. It is well known how the free oxygen of the air readily enters into chemical combination with non-oxidised or low-oxidised substances, especially if these materials are presented to it in the presence of moisture.* The resulting compounds, or oxides, are, generally speaking, much bulkier than the original substances, and quite different in nature and properties. Carbon dioxide (carbonic acid gas), ever present in air in solution in watery vapour, is a powerful atmospheric solvent agent, and its action is most potent in bringing about the decomposition of felspathic and calcareous rocks. Water impregnated with this gas has its solvent power greatly increased, and when water so charged oozes into or through rock masses, it gradually dissolves out certain constituents, such as alkaline silicates, or calcium or magnesian carbonates, and so leads to the disintegration of rocks in which any of these substances may exist. Frost, too, is a most active soil-forming agent. During the winter months rocks are broken up, and fragments more or less crumbled, by the freezing and consequent expansion of the water which fills their fissures, cracks, and cavities.

It will be remembered how granite, one of the hardest of rocks, is decomposed.† It is made up of the three minerals, quartz, felspar, and mica. Quartz is simply an oxide of silicon, and is very hard and difficult to decompose; but felspar is a more complex compound, somewhat softer than silica, and liable to be decomposed under the weathering action of the air and other natural forces. There are several varieties of felspar; but each contains the metallic element aluminium in combination with silicon and oxygen, forming aluminic silicate, associated with variable proportions of some one of the silicates of the alkaline metals, potassium, sodium, calcium, or magnesium. Under the ever-acting influence of the carbon dioxide in air, rain, or moving water, the alkaline matter in the mineral is slowly dissolved out, and may be entirely or partially washed away, leaving behind a residuum of more or less pure clay or silicate of alumina. Under ordinary conditions, it very seldom happens, however, that pure clay, or kaolin, is formed, as the aluminic silicate is almost always mixed with the silicates of potash, soda,

* "Science for All," Vol. II., p. 42.

† *Ibid.*, Vol. I., p. 250; Vol. IV., p. 17.

lime, or magnesia, and often coloured, too, with some oxide of iron; indeed, pure clay being an insoluble compound, it is entirely worthless as an agricultural soil, as it would be absolutely unable to afford any nourishment whatever to plants. While this decomposition of felspar is going on, the little grains of quartz are released, and either mix directly with the clay, and thus modify its character, or are carried off by running water to form river-sand.

Respecting the mica, it is also essentially a silicate of alumina in combination with potash, soda, magnesia, lime, oxide of iron, or other substances, in proportions varying according to its variety. This mineral may suffer partial or complete decomposition, or particles may be washed away by running water in company with the sand. The complete chemical percentage analyses of a piece of granite and a specimen of basalt are here given, as it is interesting to observe that both (one a whinstone rock, and the other a volcanic product) contain all the inorganic ingredients necessary for the production of a fertile soil, only they exist in the undecomposed rock in a locked-up or unavailable condition, in consequence of their insolubility:—

	Granite.	Basalt.
Silica	72·0	43·0
Alumina	16·0	14·0
Ferrous oxide	1·5	15·3
Lime	1·5	12·1
Magnesia	·5	9·1
Potash	6·0	1·3
Soda	2·5	3·9
Phosphoric Acid	Traces	Traces
Water	—	1·3
	100·0	100·0

Where the products of rock decay are not carried off, there a soil will be gradually formed; and upon it, at first, some of those lowly plants depending more upon food brought to them by rain than upon that which may be absorbed from the earth will establish themselves and thrive; dying, their bodies rot on the scanty soil, and thus not only add to the depth of earth, but, by yielding up to it important organic materials, so enrich it that plants of higher organisation will in time be able to establish themselves upon it. Such a soil as this, which has been supposed to be formed on the spot, will, if derived from granite or any similar rock, be obviously a mixed soil: that is, it will contain sand and clay—clay with a small proportion of soluble salts of potash, soda, lime, magnesia, oxide of iron, and other substances, intermixed with a certain amount of organic matter. Rock fragments, varying in size from sand particles to stones of moderate size, will also be found more or less freely scattered throughout the soil. These stones may, by the way, be looked upon as reserve materials from which the soil, by their slow decay, is gradually, but constantly, deriving fresh soluble matter, necessary for the nutrition of plants. A soil of this composition is known by the name of a "loam," and it may be taken as a good typical example of a fertile soil, as in it we have all the inorganic elements required by plants, and these, too, in a soluble condition.

Taking, then, a clod of loamy earth, its rough general composition may be easily made out by a mechanical analysis. The clod is first thoroughly dried, and then weighed. When pulverised, all the stones are picked out and placed aside. The powdered earth is weighed (the loss of weight noted, as representing the weight of the stones), and then placed in a metal or porcelain pot or dish, and submitted to a heat strong enough to burn away all its organic matter. When cool, it is again weighed, and the difference in weight noted, as representing the amount of organic matter which was present. (Or a fractional quantity of the soil may be taken and burned in a spoon, and the proportion calculated.) The soil is next placed in a tall vessel, into which a stream of water is allowed to slowly flow; by stirring the water the particles of earth are thoroughly separated, and by the time the vessel is nearly full the whole of the earth is in a state of suspension in the body of the liquid. After allowing the water to remain stationary for a few seconds, so as to give time for the heavier particles of sand to sink, the muddy water, containing the smaller and lighter particles of clay, is poured off, and the washing process repeated until the sand is quite clean, and the water to be poured away perfectly clear. By now weighing the dried sand, the average amount of this substance may be ascertained, while the amount, represented by the deficit in weight, of all the other ingredients combined, from the weight of the original lump, will, of course, give the average amount of clay.

The next important thing to know about a soil is the percentage of soluble matter that it contains, as its fertility and consequent value as a crop-producer depend very much upon this particular. A known quantity, by weight, of dried soil is taken, and subjected to a process of water maceration for several hours, or perhaps days, stirring it as often in the meantime as may be convenient; or,

if an immediate determination is desired, the mixture may be gently simmered for an hour or so, until sufficient time has been given for all the contained substances soluble in water to be dissolved out; then, after allowing it full time to settle, the clear liquid is poured or filtered off, and the moist earth dried and weighed; the loss in weight gives, of course, the amount of soluble matter that was present in the sample. There is, however, in all soils a further per-centage of matter which, although not soluble in rain-water, may be dissolved out through the agency of acids. The substances that may be removed in this way represent materials which, although not quite ready for immediate absorption by plants, are yet ready to be slowly converted into an available condition by the continued action of those forces which brought about the formation of the soil. But the great bulk of the soil is made up of substances insoluble in both water and acids, as the following analysis of a soil from Midlothian, made by the late Dr. Anderson, will show:—

	Surface-soil.	Sub-soil
Substances soluble in water	0·2319	0·2630
,, ,, acids	8·8600	6·5320
,, insoluble	78·2910	87·1210
Organic Matter	12·7340	6·3800

From this it will be seen that only a very small per-centage of the entire mass of the soil is really of instant use to the plant, and that the maintenance of its fertility in the event of cropping depends directly upon the less easily soluble materials of the second group of substances in the table. The totally insoluble substances of the third group are not, however, absolutely useless as plant food, but may be looked upon as the reserve material for use in the distant future.

There is yet another important matter to be determined respecting this clod of typical earth, and that is its chemical composition. A chemical analysis of a soil is sure to reveal whether or no it contains all the materials necessary for plant food, and whether any one or more of these materials exist in insufficient amounts. It also tells whether there are present in the soil substances which might be injurious to the healthy growth of crops, and is, furthermore, a valuable aid to the farmer in his selection of artificial manures.

A good loamy soil was found, upon an analysis made by Playfair, to contain the following substances in the proportions stated:—

	In 100 parts.
Potash	0·8
Soda	1·5
Ammonia	·0
Lime	1·28
Magnesia	1·12
Peroxide of Iron	3·41
Protoxide of Iron	·0
Protoxide of Magnesia	·0
Alumina	3·58
Phosphoric Acid	·38
Sulphuric Acid	·09
Carbonic Acid	·92
Chlorine	trace
Soluble Silica	·0
Insoluble Silica in clay and sand	81·26
Organic Matter	2·43
Water or Loss	3·23
	100·0

From this table it will be seen that a good loam contains all the essential inorganic ingredients, the existence of which in a soil, as has been stated in a former paper (p. 252), is so necessary for the proper support of plants. The fertility of a soil, it may be here repeated, depends upon the presence of all these essential substances, and the absence of any one of them will produce a state of absolute barrenness. Each of these essential materials, again, must be present in a soluble condition, and in sufficient abundance to supply the full needs of the particular crop to be sown.

Further, all fertile soils possess the power of retaining soluble plant food, thus preventing the valuable constituents contained in the manure applied to it from being washed or drained away. This power is said to be largely due to the presence of certain important chemical compounds, called double silicates. The clay of the soil is an ordinary silicate—a silicate of alumina—and it seems that portions of this may, under certain circumstances, chemically combine with another base, say soda, and form a double silicate—a silicate of alumina and soda. But it has been shown by experiments that this soda may be displaced by lime, if a salt of that substance is allowed to be brought into contact with its double silicate, the result then being the formation of a double silicate of lime. For example, suppose a flower-pot is filled with earth containing the double silicate of soda, and water having the sulphate of lime in solution is gently poured upon it until it just begins to drip, and the drippings collected and chemically tested, it will be found that the water now contains the sulphate of soda, the lime having been arrested in its passage through the soil.

The action may be represented thus :—

Silicate of Alumina and Soda.	Silica Alumina Soda	Silica . . . . . Alumina . . . Lime	Silicate of Alumina and Lime.
Sulphate of Lime.	Lime Sulphuric Acid . .	Soda . . . . . Sulphuric Acid	Sulphate of Soda.

Here, by mutual exchange, the lime has taken the place of the soda in the silicate, and the soda the place of the lime in the sulphate. The lime, however, may be displaced in the same way by a salt of potash, and, finally, the potash may be removed from the silicate by ammonia or an ammoniacal salt; in other words, it seems that a rarer or more valuable plant food constituent is able to displace a constituent of less use to the plant from a double silicate: for ammonia is of more value in this respect than potash, potash than lime, while soda is least valuable of all. A soil, therefore, that contains any of these double silicates is able to hold all the most valuable fertilising matters that may be applied to it, and will only give them up when required by the plant.

Another condition of fertility is that there should be a proper depth of loose, moderately fine earth, sufficiently open to allow an easy passage for water, and perfect freedom of air to and from the soil. The presence of stones of moderate size is, to a limited extent, very desirable. To a light soil they give firmness, and render a heavy soil more open and friable. By radiation they tend, in summer, to keep the land cool, while at other times they are often extremely useful in protecting very young plants from the force of the wind.

Having thus learned, from a lump of loamy earth, the origin, physical properties, and chemical composition of a typical soil, together with its more important conditions of fertility, attention may now be well directed towards other kinds of earth, commonly met with in fields and garden-land.

As has been before observed, the nature of the soil in any one place will in most cases depend upon the kind of surface-rock occurring in the district. As far as the sedimentary rocks are concerned, these occur, as they have been deposited, in a regular succession of layers, from the oldest to the most recent. They are not, however, arranged in horizontal layers, each extending across the whole country, but are inclined at varying angles, their ends cropping up to the surface in regular succession, and spreading over areas varying very much in extent. A traveller walking from London to Birmingham, for instance, would in his journey pass over the upturned edges of several very different kinds of strata, and he would notice the various distinct alterations in the character of the soil as he passed from one geological formation on to the next. The distribution and comparative surface extent of the formations extending from London to Birmingham may, however, be better explained

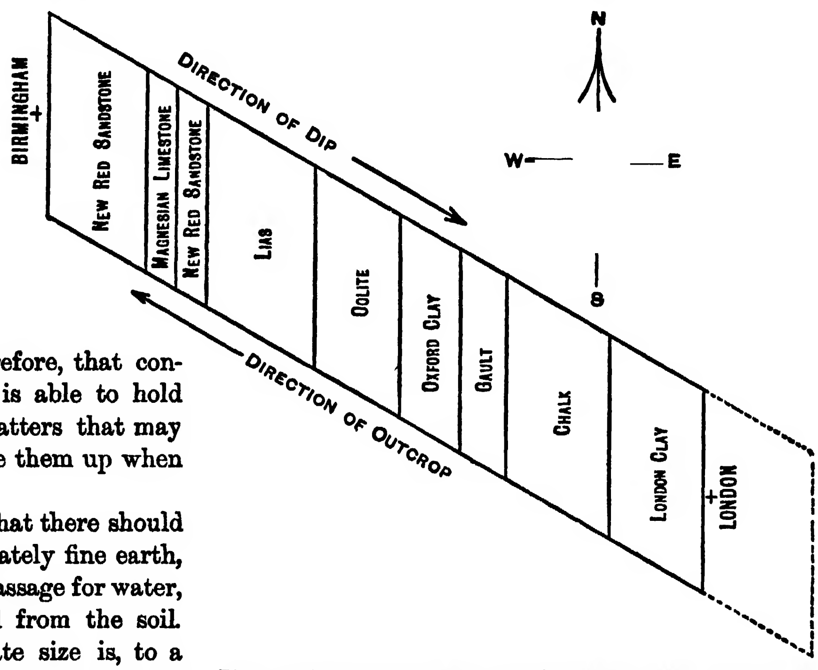

Fig. 1.—Diagram showing the chief surface-forming Rock Formations from London to Birmingham. Scale, 28 miles to the inch.

by means of an illustration. If nine cards be taken to represent the nine different formations occurring between these two places, and arranged so that only a certain extent of one end of each makes its appearance at the surface, the top card will represent the district of London, and the bottom one the vicinity of Birmingham. Placing the arranged cards on a table in their proper positions (north-west by south-east), it will be seen that London stands on what represents the more recently formed land, and that all the different strata "dip," or are inclined towards the south-east. Fig. 1 shows the cards arranged in the way indicated. The soil on the London Clay is a brown or bluish-gray tenacious clay, very difficult and expensive to work, but yielding, under skilful cultivation, very good crops of wheat. The particles of all clays are in a very fine state of sub-division, and when moist, cohere rather strongly together; hence clay

soils, when wet, are soft, plastic, and easily moulded by the hand. Under foot, they are soft, slippery, and tenacious, in consequence of which walking is made a most fatiguing exercise. When dry, clay is hard and tough, and in the field very liable to crack into deep fissures during periods of drought.

The chalk yields a light, thin, calcareous soil, very easy to work, and particularly well adapted for the growth of leguminous crops, such as clover, vetch, and sainfoin. A rich soil is formed where this formation rises from beneath the London Clay, and also where it joins the Gault, farther on. Indeed, the soil formed at the junction of any two formations is much more fertile than the soil occupying the surface of either of them. A bluish clay soil is found on the Gault, and a rather poor clayey soil, difficult to work, occurs over the next formation, the Oxford Clay. The Oolitic yields a very variable soil, often of good quality, but sometimes light and poor, and only suited for sheep pastures. Passing over the blue clays of the Lias, and coming to the New Red Sandstone formation, a rich, deeply-coloured, red soil is reached, and one generally very favourable to agricultural operations; then, after crossing the variable, but, on the whole, rather poor, soils of the Magnesian Limestone district, the fertile land of the Red Sandstone formation is again reached, which from here extends, as we see, to the suburbs of Birmingham.

The geology, therefore, of a country determines in most cases not only the mechanical nature and surface extent of its soils, but their respective chemical compositions and productive powers as well. In some cases the natural barrenness of an unproductive soil may be more or less completely remedied. The cause of barrenness, however, in any particular case must be carefully ascertained, as this condition may arise from one or more of various causes. For instance, certain injurious compounds—such as salts of iron, sour acrid organic matter, common salt, or other saline substances—may be present in the soil, preventing vigorous growth, and producing unhealthy conditions in plants. The subsoil only may contain the obnoxious matter, but still the plants are unable to live out a healthy life, and are too weak to withstand the attacks of disease germs. By exposing the soil to the long and full rigour of winter weather, these substances may be altered into harmless compounds. The presence of stagnant water promotes the formation of injurious decomposition products, and also prevents that free supply of oxygen which is so necessary to all fertile soils. In soils, too, where no natural drainage exists, in addition to the prevention of proper ventilation, the land is apt to be kept too cold, owing to its loss of heat by evaporation. Unless the soil has proper warmth, the herbage is prone to grow woody, or "wirey," and non-nutritious. Again, a free mechanical condition of soil being necessary—not only for the downward passage of water, but also for roots as well—the existence of hard or tough layers (the plough-pans and lime-pans of the farmer, for example), preventing this freedom of passage, is sometimes a cause of barrenness. The only remedy in such a case is to break up the hardened accumulations, and expose the clods to the action of the air. But very often the sterility of a soil is due to the absence—or occurrence in too small an amount—of some one or more of the essential inorganic plant food constituents.

Here is the result of an analysis of a barren sandy soil, which should be compared with the analysis given above of a fertile loam :—

Silica and Sand	96·0
Alumina	0·50
Oxide of Iron	2·0
Lime	0·01
Magnesia	trace
Potash	—
Soda	—
Phosphoric Acid	—
Sulphuric Acid	—
Chlorine	—
Organic Matter	1·49
	100·00

Barrenness, again, may be due to exhaustion of the land, from the removal by growing crops of excessive quantities of available plant food, as has been shown in a previous paper (p. 254); but, as is also explained in that article, one never-failing remedy is the application of farm-yard manure.

Proper and continuous cultivation may however, in most cases, restore renewed fertility to such soils as have become barren through exhaustion. As has been pointed out, the soil contains a comparatively large amount of fertilising substances, soluble in acids, and these, by sufficient exposure to atmospheric agencies, may be slowly rendered available for plant use; it is therefore of the highest importance that all pieces or tracts of arable land should, when convenient, be hoed, dug, ploughed, or otherwise broken up in the autumn time, and left in all their roughness exposed

throughout the winter months to the action of the air, rain, and frost. Then, not only are many of the less soluble matters rendered more soluble, and previously fixed alkaline substances released, but the soil is thereby rendered more friable, and becomes mechanically better fitted to support plants by offering less resistance to roots in their search after suitable food.

It has thus been seen that the solid rocks constituting the surface of the earth contain all the essential inorganic food materials of plants, securely retained by their mineralogical constituents in the closest chemical combination; that portions of these rocks, wherever exposed, must inevitably suffer decomposition from the slow, yet potent and never-ceasing actions of certain natural forces; and that the accumulated products of such decay constitute the more or less fertile soil, from the ready soluble materials of which the growing plant derives its necessary food.

THE RISE OF THE ORGANS OF SENSE.

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THE title which we have selected for this essay will at once suggest to our readers that we mean to trace the organs of sense along the lines of the historical method of investigation, or, in other words, to examine into the present conditions of our own sensory organs by detailing the way by which they have become developed into what they are; to use, in fine, the results of the modern process of the study of animal development. We must not, however, forget that "history repeats itself," and we shall therefore use also the comparative method, in the trust that among some of the lowlier animals we may find some indications of the course of those processes which, in ourselves, have become more or less obscured.

On a previous occasion (Vol. II., p. 309) we promised "to develop in greater detail the striking aphorism that 'Touch is the mother of all the senses;'" that promise we shall now do our best to redeem. The truth thus expressed can easily enough be put into another set of words, which will at once be seen to be only another method of expressing the same doctrine; sensations and sense-organs are first of all associated with the most external portion of the body. Like many other great truths, it is comprehensible when distinctly stated, but, like other truths, it is frequently obscured by secondary changes, which seem to affect it. The important sensory parts of our eyes or ears are far enough from the surface; the sensient brain and the conducting nerves and spinal cord of man are separated by wide tracts of tissues or firm cases of bone from that investing layer of skin which alone, with its organs of touch, comes into direct contact with the outer world—with that world from which alone can we gather all the lessons which will enable us to walk "surefootedly" with such an organisation as we have acquired.

If we take the simplest condition of the highest of living animals, or if we choose the adult condition of the very lowest, we find in both cases a more or less simple mass of a complex chemical substance, or collection of chemical substances, to which all naturalists now apply the term "protoplasm," a word already sufficiently familiar to the reader. The first complication that arises in either case is essentially similar; if the little mass of protoplasm remains single (as in the common *Amœba* already described) the outer becomes more dense than the inner part; if the single egg divides into several pieces, some soon get to be placed externally to the rest. In the one case you have an *ectosarc* and an *endosarc*, and in the other you have an *epiblast* and a *hypoblast;* but in both cases you find that the part which is in contact with the outer world presents some considerable points of difference from that which is shielded from the direct influence of external agencies.

This is the first step in what is technically known as the process of "differentiation." When you proceed further you find that of the external layer a part becomes hardened, to act as a defensive organ for the enclosed cells; other parts become modified in the direction of becoming more sensitive than the rest. Certain cells become provided with delicate sensory processes, and remain on the surface of the body; or they do not get these projections at once, but first of all sink away from the surface of the body, and become separated off from it.

In ourselves, and in many other animals, this process of separation takes place in the following way: the cells which lie along the middle line of the back thicken, and gradually dip down so as to

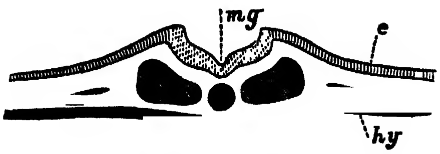


Fig. 1.—Development of Spinal Cord of Bird. (*After Quain and Sharpey.*)
mg, Medullary Groove; *e*, Epiblast; *hy*, Hypoblast.

form a concavity when looked at from above (Fig. 1); cells grow over this cavity, and the cavity itself becomes converted into a circlet of cells, surrounding a small hole. And now we come to a most remarkable point: the lowlier forms of worms

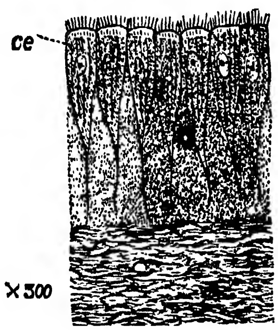


Fig. 2.—Epithelium of the Central Spinal Canal of Man. (*After Stricker.*)
ce, Ciliated Epithelium.

have the whole of the outer covering of their body provided with those delicate, hair-like projections from the cells which are universally known as *cilia.* The developing mammal or bird has no such processes on the outer surface of its body at any time of its life; but in children, at any rate, the cells lining the walls of the hole just mentioned are always provided with these delicate cilia (Fig. 2), and give, as it were, a kind of far-away echo of an earlier and simpler life. The cells, which thus grow in, come in time to form the spinal cord of the higher animal, and those in the more anterior portion form the rudiments of that large mass of nervous matter which is known to us as the brain. As these cells have been pushed in from without, and have then so grown as to form a complete circle, it is obvious that the cells which were primitively the more are now the less external, or that, in other words, the relations of two layers of cells have become completely reversed. This is, as we shall soon see, a point which must especially be borne in mind.

What has been briefly detailed will be sufficient to bring before the reader the great and important truth that the brain and the spinal cord are parts which, in the course of development, make their way from without inwards; that a skull and a vertebral column are, later on, developed for their protection does indeed complicate the history, but we must not allow it to obscure this salient and instructive fact.

When we compare the history of a complex form with the adult conditions of one that is very much simpler, we find ample evidence to support us in the position which we ought now to occupy. We all know that we have only to examine a starfish on its lower or white side to be able, the moment that we push aside the sucking-feet which occupy the groove of every arm, to find the nerve-cord which runs along every ray. To this attention has been before directed when the starfish itself was under examination (Vol. III., p. 301). But what is true of the starfish is to some extent true also of its ally, the sea-urchin, in which delicate nerve-fibres are to be detected on the *outer* side of its firm and apparently closed "test" or shell. Just as striking examples are to be cited from among the lower groups of the "worms." A comparatively new form, discovered by its describer near Messina, is said to have its central nervous mass "merely indicated as a thickening of the integument," and "the epidermis, the nervous system, and the sensory organs stand in closer relations to one another than they do in the more differentiated forms." What is true of this *Protodrilus* of Dr. Hatschek is just as true of the simpler Nemertean worms described by Hubrecht, where the nerve-trunks and the brain lie quite close to the surface of the body, and in which there is an investment, as it were, of nerve-fibres for the whole of the body. In no group, however, are more convincing demonstrations of the intimate connection of the investing and nervous layers to be found than in that which includes such comparatively lowly forms as the jellyfish and the sea-anemone; various observers, and notably among them the brothers Hertwig, whose industry must be a by-word even among German naturalists, have, by this time, repeatedly shown that the nerve-cells and the nerve-fibres lie just below the outer covering of the body, and that they still retain the very closest connection with it.

The simplest form of all the group just mentioned is the common fresh-water *Hydra*, the chief characters of which will be known to every reader of these pages; most, too, will doubtless have heard

of those special cells to which, some ten years ago, their discoverer, Dr. Kleinenberg, gave the name of *neuro-muscular* cells. Much discussion has arisen around these bodies. Professor Jeffery Parker writes of them thus:—"The simplest and most reasonable way of looking at these structures is that adopted by Dr. Michael Foster, and illustrated in the diagram at the beginning of the third chapter of his 'Text-book of Physiology.' These show clearly enough that the ectoderm cell of *Hydra*, with its muscular process, is the equivalent of what, in the higher animals, becomes sensory-cell, sensory-nerve, nerve-cell, motor-nerve, and muscle-cell. So that a fairly logical term might be made by speaking of epithelio-neuro-muscle cell; but, fortunately, it is unnecessary to employ any such cumbersome term, and quite sufficient to speak of ectoderm cell with contractile process."*

We cannot pass from this interesting and instructive group without saying a few words, by way of reminder, on the results of the remarkable experiments, already referred to,† which Mr. Romanes has instituted on living jelly-fishes. Not only are these *Medusæ* excellent subjects for physiological investigations into the characters of the nervous system, but they present in many points a very striking agreement with the higher animals. For our present especial purpose it is very important to know that, if the margin of the "bell" of a jellyfish be cut away, the active movements which up to that time the animal has been exhibiting completely cease. Most of us know that the common form *Aurelia* is provided at eight equidistant points of its "bell," or disc, with special structures, which are spoken of as the marginal bodies. If these be removed, all spontaneous movement on the part of the animal comes to an end. At the same time, it is to be noted that in this very lowly form all the tissue just underlying the lower surface of the umbrella, or "bell," exhibits the most remarkable physiological property of nervous substance—that, namely, of "conducting stimuli to a distance." Put into the kind of language we have already used, we find that near the very bottom of the animal kingdom there is no nervous tissue distinctly differentiated; or, in simpler terms, nerve-fibres are not yet to be clearly distinguished from their surrounding parts.

This, which is true of *Hydra*, is not to be taken as meaning that some quite distinct indications of nervous structures have not been made out in the jellyfishes, but only that a system of conducting fibres, similar to what is seen in ourselves, is very far from being developed at the other end of the animal series. We should, indeed, be ungrateful to such distinguished students of microscopic arrangements as the brothers Hertwig and others, if we did not remember what they have done in finding distinct nervous tissues in the *Medusæ*.

For the purposes of easy classification, we may speak of these forms as being "covered-eyed" or "naked-eyed," and it is necessary to distinguish them, for there are some important points of difference. In the former a veil runs all round the disc, and along the line of its insertion there are to be found two bands of tissue, in close connection with the external epithelium, and never, even in the most complex cases, separated from it. In the epithelial layer itself, and connected by processes with the nerve-ring, we find a number of sense-cells, which have a delicate sensory process projecting freely from them to the exterior. In the naked-eyed forms there is no such ring of nervous matter (and there is, as a rule, no velum), but the epithelium becomes at eight points enlarged and swollen, to form those special nerve-cells to which we usually apply the term of *ganglia*. Again, it is to be noticed that the connection with the outer or investing layer of the body is most intimate.

It is to be hoped that we have now accumulated sufficient evidence as to the close connection which exists between the general nervous system, whether in the young of highly-organised or the adult of more lowly forms, and the general covering of the body, and that we may now pass to a study of the different sets of sense-organs. Here we purpose to deal in detail with the eye and with the ear; but the nose, and the organs of taste and touch, will doubtless afford some instructive examples of the truth of the aphorism with which we started.

First, then, we will take the history of the development of the eye of one of the higher vertebrates, such as man himself. This complex organ consists, as most of us know, of two sets of parts—one, such as the cornea and the lens, are thickenings of the outer layer; the essentially sentient part is, in the vertebrata, *an outgrowth from within*. It may seem somewhat extraordinary to put into italics a statement which, at first, can hardly seem to be anything else than a most convincing proof of the erroneousness of the doctrine with which we started; our readers must, nevertheless, give us the credit, on this occasion at any rate, of knowing what we are about. The study

* "Proceedings of the Royal Society," 1880, p. 62.

† "Science for All," Vol. I., pp. 177, 178.

of this outgrowth from within is probably the most convincing proof that can be given of the value of studying the development of an animal through all its stages.

It will be remembered that at the commencement of this essay we directed attention to the way in which the spinal cord and brain of the back-boned animals were developed, and we showed that a thickening from without grew inwards,

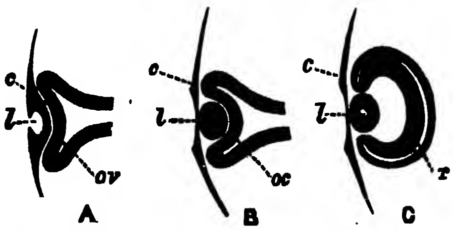


Fig 3.—Development of the Eye of the Chick. (*After Quain and Sharpey.*)

c, Cornea· *l*, Lens; *r*, Retina; *ov*, Optic Vesicle; *oc*, Optic Cup.

formed a circlet of cells, and became separated from the outermost layers of the body. Well, in the brain or anterior region of this ingrown group of cells, there appears a swelling, which pushes its way outwards till it comes in contact with the external epithelium. This swelling, or optic vesicle, is distinguished as *ov* in A of Fig. 3. This outgrowth from the brain is, then, really a development of a set of cells which owe their origin to the epiblast, or outermost layer of the developing embryo. Once again we beg attention to the fact that the cells have been turned inside out. Fig. 3, A, shows very well the gradual thickening of the epiblast to give rise to the cornea, *c*, and the lens, *l*. As the lens grows in size it pushes backward the outer wall of the optic vesicle, itself becomes separated from the cornea, and comes to lie in the cavity of the optic cup; the walls of the cup or vesicle, grow closer and closer together, and the cells which form it become converted into the *retina*, which is in connection with the brain by means of what is really the stalk of the vesicle, but which, in the adult, becomes the *optic nerve*. Enough has been said to show how the constituent parts of the human eye become developed, and to explain their relations to one another; it is needless, in the concluding pages of this work, to recall to our readers the structure of the adult human eye.

Those who remember the details of the microscopic structure of this eye, need not be reminded that if we make a horizontal or equatorial section through it, the structures which lie farthest from the light or from the cornea are the "rods and cones," or the truly sensory parts of the eye. (Vol. III., p. 116.) This is not the ordinary case in any one of the invertebrata, as they are often called. If we take a crayfish, we find the rods just underlying the corneal thickenings. If we examine the curiously elaborate eye of a cuttlefish, we find a kind of vitreous chamber, and closest to it we find the perceptive portion of the optic apparatus. Some of the marine worms, again, have very complex eyes, but here, just as in the cuttlefish, the sensory parts, or layer of rods, are found nearer the light than the layer of pigment; in other words, the relation of parts in the eye of an invertebrate is exactly the opposite to what it is in that of a vertebrate. We need hardly explain how this has happened, for twice already have we had occasion to refer to the turning inside out of the cells which occurs in the development of the vertebrate spinal cord, and we have just shown that the retinal part of the eye is developed as an outgrowth from the anterior part of that body. The other side of the truth which we may learn still remains to be definitely expressed in words: the arrangement of parts which is seen in the animals without back-bones is due to the fact that their sensory organs owe their origin directly to thickenings of the investing cells, or cells of the epiblast.

When we pass to the other end of the animal series, we find, just as we did when we were dealing with the general nervous system, that the eye of the adult jellyfish bears a close resemblance to an early stage in the developmental history of the higher forms. The eyes of the "eyed" Medusæ consist either simply of special areas of sensory cells in the epithelium, which are surrounded by a layer of pigment, or, in the more complex, of these and of an additional body, in the shape of a lens, which is formed from a thickening of the outer cuticle. It will be better to refrain from entering into any detailed account of the eyes of the lowlier "worms," and to one point only will we here direct attention—the association of the eye with spots of pigment. This is so far of significance, as it satisfies us as to the close connection with the outer world that the sensory, like the colour-containing cells, must have had.

But we may remind the reader that the "vermes" give ample evidence of the fact that eyes are parts that owe their origin to the influences of the outer world. We have only to reflect that they may, as in *Polyophthalmus*, be developed on every one segment of the body; and that in others, as in the case of the burrowing earth-worm, they may be altogether absent. Light, then, acting on some of

the cells of the outer layer of the body, has produced in them a certain set of changes, which have not only become inherited, but have gradually given rise to highly complex pieces of refractive apparatus, accommodating muscles, accessory fluids, and a sensory organ so elaborate in its minute details as to require the most ingenious methods of research, and very high powers of the microscope for their complete elucidation.

The ear, no less than the eye, will be found to present us with very striking illustrations of the law on which we are now insisting so much. As before, we will commence with a history of the development of the complexly arranged and deeply situated ear of the higher vertebrata.

It will be remembered (Vol. IV., p. 235) that this organ consists of an outer passage, a middle, and an inner ear, and that the last of these, which is alone the sensory portion, contains a so-called labyrinth, and that the labyrinth itself is membranous, and is contained within an "osseous labyrinth." Between these two there is a fluid known as the *perilymph*, and within the inner a fluid—known as the *endolymph*—is again to be found. Three semicircular canals, and a portion which is coiled on itself, like a snail's shell, and is known as the *cochlea*, form the more important parts of the inner ear. On the walls of both parts of the membranous labyrinth we find special sensory cells, which are supplied by branches of the auditory nerve. This auditory nerve arises directly from the hinder portion of the brain. So that for the ear, just as for the eye, the nervous supply is in immediate relation to the central organ of sensation.

Complicated as the arrangements are, it still remains true that the ear commences as an ingrowth of cells from the outer layer of the body. Very early in life we may find, just behind those three enlargements of the central nervous cord which are the first indications of the future brain, a shallow, wide pit which grows down into the intermediate or middle tissue of the embryo. The old history is repeated: the pit rapidly narrows at its mouth, moves away from the surface of the body, and forms a more or less pear-shaped and closed sac—the so-called *otic vesicle*. In this there appear several swellings or enlargements. One of these gradually gets coiled on itself to form the cochlea, while others give rise to the three semicircular canals. The surrounding parts are fashioned out of the intermediate tissue into which the otic vesicle has forced its way; but the sensory cells, or the epithelial layer of the membranous labyrinth, to which are sent the branches of the auditory nerve, are always the direct descendants of those cells which primarily lay on the surface of the body, which then formed the floor of the pit, and, later on, the walls of the simple otic vesicle.

A very considerable difference between the eye and the ear remains to be pointed out. No part of the ear owes its origin to a secondary outgrowth from the brain; all the sensory parts are direct results of the first invagination, none are secondarily epiblastic in the sense in which the cells of the retina are so. While, then, we have in the ear a simpler story of development than we can tell of the eye, a difficulty is presented to us in another direction, and that is, how do the brain and the ear become connected? In the case of the eye the stalk of the optic vesicle forms the optic nerve, in the case of the ear the auditory nerve is developed out of the intermediate tissue. Further into this difficult question we cannot here enter, but it is obvious that we are now on the threshold of one of the most obscure of problems, and that is the means by which the sensory parts on the surface of the body have come into connection with one another and with the central nervous mass.

When we come to study the less highly organised vertebrata, we find a number of lowlier stages permanently represented in the adult ear. So far as we know, the lancelet (*Amphioxus*) is without an especial auditory organ at all, the hag (*Myxine*) has but one, the lampreys (*Petromyzon*) have only two semicircular canals, though three are always found in all the rest of the vertebrata. In the lampreys and hags, as Dr. Günther tells us, "the labyrinth is enclosed in externally visible cartilaginous capsules laterally attached to the skull;" in the dog-fish (Vol. IV., p. 181, Fig. 4) three prominences, corresponding to the three semicircular canals, can be made out on the surface of the skull, and careful examination will reveal the fact that there is, even in the adult, a small opening, the still persistent primitive orifice of the auditory sac. A comparative study of the cochlea tells us again the same tale; it is in mammals only that it is completely coiled on itself, and even in the lowest of them we only find the end bent up. A similar arrangement to that of these mammals (of the Water Mole and Porcupine Ant-eater order) is found in birds and in reptiles; in the frogs it is only an enlargement, and in fishes the enlargement is still less distinct.

If with a bound we pass to the other end of the series, we find the very simplest of auditory

organs in some of the Medusæ. Along the line of attachment of the "veil" to the disc we find a series of pits, the orifices of which are directed downwards. The cells on the convex surface of these bodies are provided by the epithelium of the upper face of the "veil," and these cells have thick walls and contain fluid. The lower face of the velum gives rise in some of its cells to minute hard bodies, and along the inner edge of each pit we find sense-cells provided with stiff auditory hairs, and continuous with the nerve ring which runs round the disc. Here then we find, in its simplest expression, all the essential parts of an auditory organ: fluid, calcareous bodies, auditory hairs, sensory cells, nerve connections. Within the limits of this group we find several stages of "differentiation." The first is that the pit is in many closed, and converted into a vesicle. In others the marginal vesicle becomes stalked, the canal in the stalk gives rise to a swelling (*ampulla*), and on the side of this ampulla there is a vesicle which again is found to contain crystals or "otoliths."

Even in so complex a form as the crayfish the auditory sac is still open to the exterior, and so distinctly enough proclaims its origin from a simple wide pit. Of the mollusca it need only be said, in the words of Gegenbaur, that "we have a permanent proof that the otocyst is developed from the ectoderm in the Cephalopoda in the presence of a fine canal, which, in many of them, leads from the auditory vesicles to the surface of the body."

The three other sets of sensory organs shall not detain us long. The tactile and gustatory senses are, of course, situated in the epidermis or epithelium; the nose is at first an open pit, and it never becomes shut off from the outer air. Something as to the comparative anatomy of the nasal canal was said on a previous occasion (Vol. IV., p. 183), when we pointed out the superficial position of the nasal groove in the dogfish, and gave a figure to compare the permanent condition of that animal with the temporary arrangements which are found in the chick (*loc. cit.* Figs. 7 and 8). A factor of very considerable importance in the development of this organ of sense must not be passed over; there can be no doubt that between smelling and breathing there is the very closest connection, and there is much to lead us to believe that the organ of the sense of smell is closely connected with that of respiration. It will be within the knowledge of all of our readers that there are, even in the highest of back-boned animals, very distinct signs of their original possession of a number of gill-slits, and some evidence has been accumulated in favour of the doctrine that the vertebrate smelling organ owes its form to the fact that it was derived from such a gill-slit. It is well known that the special olfactory or smelling cells are situated on a folded *Schneiderian* membrane. These folds in the dogfish are, as Dr. Marshall has pointed out, very similar in form to "the series of folds which, arising from the sides of the visceral clefts, form the rudiments of the gills," and it is curious to observe how completely the two sets of parts resemble one another in structure, and in the characters of their nerve-supply. Whether these results shall be shown to be correct or not, the relation of breathing to smell affords us only another example of how sensory organs owe their origin to the action of influences acting on parts exposed to the outer world. Did space admit we might have drawn somewhat similar conclusions from the study of the mollusca; here we can only say that in animals in which there are no special respiratory organs no indications have as yet been observed of the presence of any special organ of smell.

We have already in earlier pages dealt with the organs of touch and taste, and it now only remains for us to see what lessons can be learnt about them by an examination of some of the lowest animals. In *Eucharis*, a form allied to the jelly-fishes, we find tactile processes, the free ends of which are beset with special cells. Provided with a delicate covering and filled with granular contents, they are separated from one another by tufts of projecting setæ; they surround and cover the so-called "tactile wart," the substance of which is chiefly gelatinous tissue, which is traversed by a number of what seem to be nerve-fibres. In the common sea-anemones, the brothers Hertwig, to whom reference has already been more than once made, find in the tentacles and around the mouth extremely fine filamentous sensory cells, which are distinctly a part of the ectoderm. These are provided with one or two processes, of which when one only is present it is directed outwards, and of which when two are present one passes inwards. Their inner ends are more delicate than their central portions, and these processes unite one with another, and are directly connected with an internal meshwork of nerve-fibres. The most important point to notice is that these cells lie directly on the surface. So, again, delicate sensory cells—"*palpocils*"—are found on the tentacles of the common *Hydra*, but they are structures which are probably familiar to most of the readers of this work (Vol. IV., p. 156); and the extreme sensitiveness of these delicate projections

must have often been demonstrated to every one of us. Had we sufficient space and time we might draw on numerous observers and observations for further illustrations, but enough has now been said to show that the investing layers of the body are in all but rare instances the seat of special organs of sense; and even where, as in the lobster, the body becomes covered by a hard carapace, or as in the oyster by a solid shell, the tentacular prolongations or the antennæ are especially the seat of a high sensibility.

We cannot, however, leave this subject without a short reference to the problem of the presence of a nervous system, as distinguished from, but as communicating with, the organs of sense. We have already spoken of the physiological properties of the tissue just underlying the lower surface of the umbrella of a Medusa, and have pointed out that it seemed to have a generalised nervous property. The students of the minute anatomy of these creatures have discovered nerve-fibres in this region, though the disposition of such fibres is, as it seems, by no means regular. In the allied *Beroë* similar observations have been made, and it has been found that the cells of the central nervous system are not collected together, but are distributed over the whole of the body; now only it remains to note that these cells are often in close connection with the external epithelium. We have just spoken of the processes which in the sea-anemone pass from the sensory cells to the subjacent nervous layer, which is scattered over the body, but which, though so scattered, is from a histological point of view, a good deal confined, for it still forms a part of the ectoderm. This nervous layer does not consist of fibres only, it contains also nerve-cells (ganglion-cells), which, from what we have now learnt as to the way in which cells make their way from without inwards, we can hardly believe to be anything more than immigrated sense-cells.

If this shall be shown to be a correct view of the known facts, it will do much to relieve the difficulties raised by a study of the development of such an organ as the human ear; it will afford a convincing proof of the truth of the aphorism with which we started; and it may, if we choose to carry it further, be found to be pregnant with wide and deep lessons as to the action of external nature on man and on animals. Much that now may vex our sensibilities, or offend our feelings, may be seen to have its rise in that general arrangement which brings sensation and the outer world into so intimate a contact; and, on the other hand, it may inspire us to fresh activities, and, knowing that now our brain itself is never, except through the senses, affected by the outer world, we may struggle to make that world more bright and cheerful, more healthy, and more refined.

SCIENTIFIC DECEPTIONS.

By William Ackroyd, F.I.C., etc.

DECEPTION by means of scientific experiment now serves only the two ends of instruction and amusement. The person who places one hand in hot water and the other in cold, and then, after a little while, dips both in the same basin of lukewarm water alternately, finds that the lukewarm water appears cold to the warmed hand and hot to the cooled hand. He is entirely deceived in his estimation of the temperature, but profits by the lesson thus learnt of the fallibility of one of his senses. So it is wherever there is deception of this kind, a useful lesson is taught, and as we shall presently show in some instances, much amusement may likewise be derived therefrom. In early times, however, deception by means of scientific experiment served only one purpose; it was a powerful instrument employed to awe the people by their rulers, and to this end, prince, priest and sage were leagued together to impose on the masses, who at times could not be impressed unless by some appeal to what they, in their ignorance, considered to be supernatural. In some of the ancient temples, votaries were occasionally treated to a sight of the gods, probably raised by optical means, and the oracular responses and weird-like voices which they likewise heard, were due, without doubt, to scientific contrivances. The means they employed would seldom deceive people now, accustomed as they are to the optical and acoustical wonders of the present century, but in a harmless way one may still practise devices, which throw the judgment entirely at fault, no matter how educated one

may be. The uninformed may be readily deceived on matters of observation alone where others would suffer no deception at all, as will be apparent in the following example.

It is easy to see that the juggler who keeps three or four balls tossing up in the air manages the feat through his quickness of eye and dexterity of hand. The trick, however, becomes inexplicable to some when performed by an acrobat standing on the back of a horse swiftly running round the arena of a circus. Why do not the balls fall behind the performer? And this entertainer of the general public would, in all probability, be unable to assign the correct reason although perfectly familiar with the truth of the fact. It is the same difficulty which leads a landsman to declare that if a weight were allowed to fall from the top of the mizzen-mast when a ship is in full motion, it would drop into the sea. When told that such a falling weight would land at the foot of the mast, he is incredulous until some sailor begins to relate his experience of how a marling-spike, a grease-can, or some other body, having been slipped from aloft by a clumsy ship-mate, fell, much to his alarm, close to where he was standing, at a point directly underneath, although the vessel was at full speed. He cannot perceive that such ought to be the case until he has learnt the first law of motion in mechanics, viz.: that every substance, if at rest, will remain at rest for ever, or, if in motion, will move on for ever in a straight line, unless some force being applied to it disturbs its state of rest, or alters or stops its motion in a straight path. The balls which the juggler has in his hands while his steed is careering round, and the weight at the top of the mast of the progressing vessel, possess respectively the same motion as that of the horse and that of the ship. And if, so far as they are individually concerned, there were no force like gravity pulling them earthwards upon removing their means of support, they would go on until the resistance of the air stopped them, and if there were no obstacle at all to oppose their progress they would move on for ever in straight paths.

To come to more decided cases of deception we may first consider some of the phenomena of sight, some of the illusions of which have already been noticed (Vol. I., p. 164). We know that a branch of a tree, or a telegraph pole, when viewed with the full moon behind appears indented, which arises from irradiation;* that a single object whose images happen to be cast upon unsympathetic parts or areas of the two retinæ which do not correspond, appears double,† and that coloured spectral images are seen when the eyes have become fatigued for particular colours. In the study of optical phenomena, one comes across many cases of deception like these, which would lead the uninitiated to declare that they saw something more or different from what really exists. With a single eye even one may see an object apparently double by the following simple device. Make two pin-holes in a piece of card-board at a distance from each other less than the diameter of the pupil, and hold a small object, like the head of a pin, not far from the eye, and view it through the two pin-holes. Two images of the head of the pin are seen, and as there is only one pin-head, the phenomenon at first sight appears rather anomalous. It is apparent, however, that the rays of light reflected from the pin-head through the holes into the eye are split into two minute pencils which are cast on to the retina to produce two separate images. The deception is therefore caused by the two pin-holes in the card-board.

The advertising genius racking his brain for some device for taking the eye and retaining the attention has occasionally hit on ways which are interesting from our present point of view. A harmless deception, which he often practises, is to have a large poster, the words of which are interspersed with others of much larger type, and which are of course easily read at a distance, while the words represented by the small type are indistinct. The words with large letters have been so chosen that when read they form a sensational announcement. Thus you may read that there is "£500 REWARD OFFERED FOR THE CAPTURE OF A POISONER," and upon going close up to the bill to learn full particulars, find that it is only a pill vendor's advertisement; or you may read at a distance that "A BLACK MAN MAY BE MADE WHITE FOR NOTHING," and find upon a nearer approach that it is simply an announcement of the advantages to be derived from the use of somebody's blacking. This is a sample of the style of thing we are describing:—

Mr. A. has the honour **TO** announce that he has just received a fine assortment of articles from the Metropolis, **ALL** of the best quality. The firms from **WHOM** they were bought are famous for the durability of their goods, and **IT** need hardly be said that our customers **MAY** feel no **CONCERN** on this head as the wear of their last purchases will have fully proved their trustworthiness.

* "Science for All," Vol. I., p. 168.

† "Science for All," Vol. III., p. 195.

This announcement, seen from a distance, would appear to read "TO ALL WHOM IT MAY CONCERN," while upon closer inspection it would at once be observed that it was only a draper's advertisement. The ease with which a person sees a thing depends of course upon its size and distance. A particular letter, for example, has to cover a certain area of each retina, in order that it may be distinctly discerned. And as the image of any given thing becomes less and less in a definite ratio, the farther the observing eye is away from it, there plainly is a limiting distance at which any particular size of type can be distinctly made out. Upon approaching one of the bills we have been describing, the limiting distance of the large type is first reached, and that of the smaller type not until the observer has got very much nearer to the bill.

Marriotte's experiment* which illustrates the fatigue of the eye upon gazing at bright colours, and the subsequent production of complementary spectral images, has likewise been employed in a slightly modified form for advertising purposes. Thus you are requested to look at the name of the advertiser in white letters on a red ground for a minute, and then to transfer the gaze to a blank white space. This white space now appears of a bluish green tint, and the name appears on it in red characters. If a small square hole be cut into a red wafer, and then this be pasted on to a sheet of white paper, we shall find on repeating the foregoing experiment that the spectral image obtained after transferring the gaze from the red wafer, with its central white square, to a sheet of white paper, is a patch of bluish green with a square of red in it corresponding to the square of white in the wafer. Hence, when a bright-coloured image is cast upon the retina it is surrounded by a complementary fringe, and therefore when the gaze is transferred to a sheet of white paper, one sees, instead of the complementary fringe of which the eye has become tired, a fringe of the original colour which was stared at.

Next to the eye, not one of the five senses is so easily deceived as the ear, and this is the more remarkable, seeing that it is the organ most used by us from the early days of childhood, when comfort is derived from a nurse's lullaby, to the days of hoary old age, when our main pleasure is in the social gossip of our friends. In fairness, however, to the ear, we must say that one kind of mistake any one may make arises from no defect of the auditory organ, but from a physical peculiarity attending the transmission of sound under certain circumstances. A single echo may be produced in such a way that one has a difficulty in saying whence the sound has come. You are standing, let us say, not far from the side of a large building, listening to the strains of a military band some distance off. The sound seems to come from the side of the building, and you look in that direction for the origin of the music when probably you ought to have looked in another direction altogether. The ear here makes no mistake, for the deception is caused by the reflection of sound from the side of the building, and is perfectly analogous to a simple case of reflection of light from a mirror. If you look into a mirror with a candle on one side of it, an image of the candle is seen, which appears to be beyond the mirror, and one totally unacquainted with the peculiarities of reflected light would imagine the image beyond the mirror to be the source of light, until by observation and reasoning he had found out that the candle in front of it was the real source of the rays. So likewise in this case of the reflection of sound, the building acts like a mirror in reflecting the notes, and knowing as we do that so much of the aërial disturbance as reaches the ear has travelled in a straight line, we look in the direction of the building for the musicians, until the accompanying and steadier strains, coming direct from the band, lead us to look in the proper direction. A mistake of this sort, however, may arise from a totally different cause, namely, the inability of our ears to tell the direction in which a sound comes to us, when that sound has been produced in a particular position with regard to the two ears. I remember a curious case in point which happened in a place of worship. It was a lovely morning in May, and the light streaming through the tinted windows lent an extra charm to the interior of a nicely-decorated and quiet country church. The assembled congregation had commenced singing the *Te Deum* when the harmony was harshly broken in upon by a voice near to me, keeping neither time nor tune, and marring entirely the pleasurable effects of the music. At last the annoyance became so distressing that I began to speculate as to who might be the unfortunate possessor of ears so deficient in tune, and of such a laggardliness, both in the singing and responses, as to be always behind the rest of the congregation. Without moving my head, it appeared to me that the unfortunate singer was somewhere about a couple of pews behind. The *Te Deum* was finished, but when we came to the *Jubilate* there was a

* "Science for All," Vol. V., p. 10.

recurrence of the annoyance, so turning round to see whence the noise came, I suddenly became conscious that the unwelcome voice was not behind, but in front of me, and that the sounds emanated from an old lady in the very next pew, who had taken up a position just opposite me. It appeared highly improbable that reflection of the sound had anything to do with the phenomenon

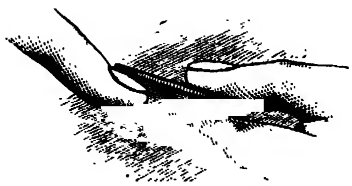


Fig. 1.—The Clicking Pennies.

here. And the solution is probably to be found in the following experiment due to Professor Crum Brown, and which may be very readily repeated.

Blindfold a person, and then make a clicking noise in various positions around his head. This may be readily done by taking a couple of pennies, and inserting a finger between them, while with the thumb and finger of the other hand they are pressed together (Fig. 1). Every time the finger is withdrawn the pennies come together, and make a clicking noise. The blindfolded person cannot always tell whence the clicking noise comes. He is generally deceived when the pennies are in particular positions, and if the performer knows which are these positions, he can ask whence the sound proceeds upon making the clicking noise, and show, for the amusement of all present, that his friend is wofully deceived. Imagine a plane to cut through the chin, nose, and crown of the head so as to separate it into two symmetrical halves (Fig. 2). This plane is the *medial plane*, and all sounds produced in the medial plane are apt to deceive. If the sound be made behind the blindfolded person he may think it is produced in front of him; and if the sound emanate from a point in front it may appear to be produced behind him. On either side of the medial plane the blindfolded person has not much difficulty in saying where the sound is produced.

In judging of the distance of a sounding body, we depend upon the intensity of the sound, taking as our standard for comparison, the sound we know the same body to produce when nearer to us. Thus when a horn is sounded, the blast we hear is far different from the faint reverberations which are reflected from distant hills, and of whose distance we gain some idea by the faintness of the sound coming from them. It will be perceived, therefore, that in the matter of distance the ear may readily be deceived, and the impression of a full band at a distance will be conveyed to the mind by a hidden orchestra very near us, playing softly. Ventriloquism is nothing more or less than the art of deceiving, by imitating as closely as possible, every variety of sound as it reaches the ear, *i.e.*, regulating the different intensities so as to produce the idea of distance as well as of individuality of sound. We need make no remarks here on the wonders which have been achieved by ventriloquists, as most of our readers will have heard practical demonstrations of them on the stage.

At the commencement we pointed out the deceptiveness of the sense of temperature, and what appears a more striking case of it still is shown in the following experiment:—Immerse the fore-finger of one hand in water at 104° F., and then plunge the whole of the other hand into water with a temperature of 102° F. The latter, although two degrees cooler, will be judged to be the warmer of the two, from which it appears that the intensity of the sensation of temperature depends not only upon the relative degree of heat

Fig. 2.—Illustrating the Term "Medial Plane."

to which the parts are exposed, but also upon the extent of surface over which it is applied. From this cause a bath which is not uncomfortably warm, when a few fingers are dipped in it, appears scalding hot when the whole body is immersed. The sense of temperature is likewise entirely at fault when required to determine which is the warmer of two substances, say a piece of iron and a piece of wood, for if they both have the same temperature, the iron will feel the hotter of the two, because of

its being a so much better conductor. A slight difference of temperature, however, between two substances of like nature is easily discerned, and we may here describe a simple but highly entertaining trick which is founded on the fact. The performer having placed his hat behind him, requests the people present to place in it three or four pennies. He shakes it up behind him, and then asks some person to take out a penny and closely examine it. He has then to pass it to the others for examination, the last one pitching it back into the hat again. The pennies are then re-shaken up, and the performer now, placing one hand behind him, picks out the penny which has been examined, although throughout the whole operation he has never seen it. When the experiment has been done some two or three times successfully, all sorts of unlikely suggestions are made as to the way in which the feat has been performed, but very seldom the right one, which is exceedingly simple. The people in handling the penny which was selected from the others, make it warm. It is therefore easy to pick it out from the others when it has been pitched into the hat again. This sufficiently demonstrates the fact that at ordinary temperatures the sense of temperature as localised in the fingers is sufficiently sensitive to discriminate between several pieces of metal so as to say which is the warmest. But for the extremes of hot and cold, touch is thoroughly deceived, a piece of frozen mercury giving a burning sensation like a red hot bar of metal.

The touch which attains to such perfection in persons afflicted with blindness is readily deceived. This is shown forcibly by the experiment of Aristotle. Cross the index and middle fingers and run them over a marble placed on the table with the eyes shut. Under such circumstances one has a difficulty in avoiding the belief that he is dealing with two marbles instead of one. The idea of roundness which has been obtained by a complex judgment, founded on the coalescence of several sensations, is here appealed to, but the usual conditions being reversed, we draw a wrong conclusion. The sense of taste may likewise be confounded by altering the conditions under which the gustatory operation is always carried on. Thus, if the nostrils be held firmly, it is impossible to distinguish between the sensations produced by applying an onion or an apple to the tongue.

Perhaps the most marvellous cases of deception the scientific man has to deal with are those which, as a rule, accompany some bodily ailment, and are produced without the immediate agency of any external stimuli. You may think you are listening to music, either vocal or instrumental, and follow the tune from beginning to end, while all the time there is no music being performed; you may fancy that you see the face of a friend who at the time may be dead or far away, and he appears to you with such reality that you call him by his name, but of course get no response: these are purely delusions of the senses which are known as *subjective sensations.* An example or two may prove interesting. Sir John Herschel gives the following from his personal experience:—"I had been witnessing the demolition of a structure familiar to me from childhood, and with which many interesting associations were connected; a demolition not unattended with danger to the workmen employed, about whom I had felt very uncomfortable. It happened to me at the approach of evening, while, however, there was yet pretty good light, to pass near the place where the day before it had stood; the path I had to follow leading beside it. Great was my amazement to see it as if still standing—projected against the dull sky. Being perfectly aware that it was a mere nervous impression I walked on, keeping my eyes directed to it, and the perspective of the forms and disposition of the parts appeared to change with the change in the point of view, as they would have done if real." Sir David Brewster, an often quoted authority on this subject, gives remarkable examples of these spectral illusions. One of these, which we may here cite, affected the auditory organ. A certain Mrs. A., with whom he was well acquainted, was standing near the fire in the hall one afternoon in December in the year 1830, and on the point of going upstairs to dress, when she heard, as she thought, her husband's voice calling her by name, "——, come here! come to me!" Upon going to the door where she thought he was, she found no person there. She returned to the fire and again heard the same voice crying out distinctly and loudly: "——, come, come here!" whereupon she opened two other doors of the same room, without finding any one. Once more she took her stand by the fire-place, and now the same voice appeared to call out in a loud, plaintive and somewhat impatient tone, "——, come to me, come! come away!" She cried out in response, "Where are you? I don't know where you are!" still imagining that he was somewhere in search of her; receiving no answer, however, she went upstairs shortly after. Mr. A. returned home in about half-an-hour afterwards, and she was greatly

surprised to learn that he was nowhere near the house at the time she supposed she had heard his voice. These are curious cases of illusion which do not affect every one, but to those who are subject to them they come with great vividness, and it requires much strength of mind to dispel them. Not less startling are the sights a man sees who is labouring under *delirium tremens* brought on by excessive drinking, for before his unhealthy vision there arise up images of demons and all manner of loathsome beasts and reptiles, which for the time being he regards as in actual existence. One person, informing the writer of his sufferings after a drinking bout of unusual length, said the "devils" took the form of a fish he was particularly fond of when he was in a sane condition, but, which in his extreme state of nervous depression, while the delirium was on, caused him an infinitude of fright by surrounding him on all sides, open-mouthed, as if about to devour him, and staring at him stonily with their fishy eyes.

These apparitions are nearly as inexplicable as the phenomena of dreams and the scientist contents himself with simply describing them as matters of natural fact, and framing somewhat unsatisfactory hypotheses to account for them. The examples we have given seem to favour Dr. Hibbert's hypothesis that spectral apparitions are nothing more than ideas, or the recollected images of the mind which, in certain states of bodily indisposition, have been rendered more vivid than actual impressions, and Sir David Brewster maintains that these recollected images or mental pictures have their place on the retinæ while the apparition lasts, in other words, that the mind's eye is the body's eye. His reasons admit of being placed before the reader very succinctly. Vision is of two kinds, *actual* and *mental*. "If we look at the façade of St. Paul's, and without changing our position, call to mind the celebrated view of Mont Blanc from Lyons, the picture of the cathedral, though actually impressed upon the retina is momentarily lost sight of by the mind; and during the instant the recollected image of the mountain, towering over the subjacent range, is distinctly seen, but in a tone of subdued colouring and distinct outline. When the purpose of its recall is answered, it quickly disappears, and the picture of the cathedral again resumes the ascendency." In a healthy state of the mind and body, the relative intensity of these two classes of impressions is nicely adjusted; the *actual* picture is in the ascendency. But under certain conditions, as when one is suffering from indisposition, the *mental* picture is in the ascendant, giving rise to the apparitions we have spoken of, which, plainly, when viewed from this standpoint, are stripped of their terror.

These things we have spoken of, and others of a like nature, which are furnished by every science, show how readily the reason may be deceived. We commonly declare with perfect confidence that we saw or heard or felt certain things, but the real truth is that we only judged that certain sensations of sight, hearing, and touch were caused by such and such things. When our judgment has played us false, as in the instances we have given, we have been without doubt victims to a kind of deception, which we have termed scientific, for the simple reason that it comes within the pale of science to analyse and ascertain all that it is possible to learn concerning these anomalous phenomena.

BIRDS' NESTS.

By R. Bowdler Sharpe, F.L.S., F.Z.S., etc.,

Zoological Department, British Museum.

THE study of birds' nests has always been far less popular than that of the birds themselves or their eggs. This is probably due, in part, to the impossibility of forming a complete collection of nests, the large size of some of the specimens rendering it extremely difficult to find accommodation for them, even in great museums. And as regards the smaller kinds, however beautiful they may be when fresh, their beauty soon fades when they are kept in a cabinet, and it most assuredly entirely disappears after they have been subjected to the process of baking in an oven—an operation which, according to many authorities, is absolutely necessary in order to destroy such insects as may be harboured by them. All the collections of birds' nests, therefore, either in public or private museums, are very imperfect, and even in the British Museum the series exhibited is not very large. It is,

ever, sufficiently complete to show many of the most remarkable forms of bird architecture, and a very curious study they present. We are at first struck by the absence of nests belonging to the great Picarian order of birds, amongst which are the familiar families of Kingfishers, Bee-eaters, Cuckoos, and Woodpeckers, for the simple reason that they build no regular nests, and this circumstance shows us that, however different in habits these Picarian birds may be, yet the fundamental character of and are a plentiful family in nearly every quarter of the globe. I am here alluding, of course, only to the nesting habits of the birds, with which this paper has to do, as there are other causes which tend to preserve pigeons from destruction, such as their timid and watchful disposition, their powerful flight, &c. What I have mentioned, however, proves that the mere fact of building an open nest with conspicuous white eggs is not in itself detrimental to the well-being of any bird, and in

Fig. 1.—Nests of South African Weaver-birds.

their double-notched breast-bone or sternum, which separates them from all the ordinary perching birds, is accompanied by an entirely different manner of nidification. It has often been suggested that as these birds lay pure white eggs, it would never do for them to build open nests, because their white eggs would be so much exposed that they would at once become the prey of monkeys or egg-eating birds or animals, and that they would, therefore, lose in the struggle for existence. One great argument against this theory has always seemed to me to exist in the nesting-habits of the Pigeons, who are a peculiarly defenceless family of birds, possessing no weapons of offence or defence, and who yet build open nests and lay only two pure white eggs; in spite of which they increase in numbers

the case of the Picarian families, we must look to other causes for their habit of nesting in holes and covered places. It is more probable that with these birds the mode of nesting is derived from the practice of a common ancestor, which most of them have continued to the present day. It must be remembered, also, that in the Picarian birds the colours are exceedingly brilliant and the females are equally brightly coloured with the males, so that if they were to build exposed nests, the hen birds would run great risk of detection on account of their gaudy plumage. There can, therefore, be no doubt that the colour of the female bird has a great deal to do with the concealment of the nest, for we see the same with many perching birds, such as Titmice, for instance, which always build in the

holes of walls, or in trees; and here again the hen is generally as brightly coloured as the male bird. There are, however, exceptions, as in the case of some Titmice, Nuthatches, Creepers, and Wrens, which always conceal their nests in holes, or, if they build in the open, construct a domed nest so as to hide the eggs; and yet they are amongst the most plainly-plumaged of birds, with hens as dull-coloured as the males. We can only account for this on the supposition that the object is to protect the eggs, which are white, or white with red spots, and conspicuous. Another exception to the general rule is witnessed in the case of the Humming-birds, which build their tiny open nests attached to the boughs of trees and lay only two white pea-like eggs; while the females can never be called dull-coloured, and are often of the most brilliant and metallic plumage on the backs. No one can examine a series of birds' nests without being struck with the wonderful skill displayed in their construction. This is especially the case with the nests of the Weaver-birds (Fig. 1) and Tailor-birds (Fig. 2), who sew a leaf together to form a bag to receive the nest, and with those of the Hangnests, who interwine grass in a most wonderful manner, even tying knots to bind the structure together more firmly. In the case of the first-named birds, the habit of weaving seems to be so innate that, even when the nests are finished and the females are sitting on the eggs, the males proceed to make nests for themselves. These "cock-nests" are not of the same purse-like shape as those built for the reception of the eggs, but are concave shelters, with a perch across the lower

Fig. 2.—Long-tailed Tailor-bird and Nest.

opening, while to the side is always attached a little lump of mud, placed there, it is said, by the bird to sharpen its bill upon, as he sits in his little dome and sings to the female while she is hatching the eggs. Nest-building is, no doubt, to a large extent an hereditary instinct in birds; but many naturalists consider that the faculty of imitation also plays a part, while it is certain that the great difference which is seen in the construction of nests of the same species, shows that some are greater adepts at the art than others; it has also been supposed that the less finished nests are those of the younger and more inexperienced birds.

"Felted" nests are difficult to understand. They are generally the work of very small birds, and are, in nearly every case, domed or purse-like in shape. They exactly resemble a piece of soft felt to the touch and are exceedingly tough. This effect of felting is produced, according to the observations of naturalists, by the continual welding together of small particles, which, at first collected in rude masses by the bird, are worked by its bill into the compact mass which excites our admiration in its perfect form.

It has been suggested that many old birds of both sexes pair off with younger birds in the breeding season, and that the older and more experienced birds impart their knowledge of nest-building to their younger mates. I cannot, however, divest myself of the opinion that the instinct of nidification is principally hereditary, and that improvements in the construction of a nest or the choice of a situation, are the result of the bird's own reasoning powers. The nesting-habits of the Tooth-billed Pigeon of Samoa (*Didunculus strigirostris*), for instance, have completely changed within recent years, and this change is certainly due to an exercise of reason; for at one time the birds were entirely ground-pigeons, and were rapidly being extinguished by the introduction of cats and rats into the islands, which devoured the birds and their eggs. But after approaching to the verge of extinction, the remnant of the species appear to have altogether reversed their habits, and to have taken to the trees both for roosting and nesting purposes, and the birds are now by no means so rare in the Samoan Islands.

It will perhaps be interesting to note some of the characteristics in the nidification of a few leading families of birds. Let us take, in the first place, the Accipitres, or birds of prey. These, as a rule, build large, open nests, in precipitous rocks or on tall trees. The eggs are generally dark in colour, but in many cases are nearly white. The female usually resembles the male, but is the larger and more powerful bird. They appear to trust mainly to their personal strength, or the situation of the nest for the defence of the latter, which is a rough and clumsy structure, with no attempt at ornamentation, unless it be in the case of the Booted Eagle, which is said to line its nest with fresh, green leaves.

All the Striges, or Owls, lay pure white eggs, which they conceal in the hole of a tree or a wall. The sexes are alike in plumage, and no attempt is made at ornamentation in the nest. The Caprimulgidæ, or Goat-suckers, build no nest at all, but lay their eggs on the ground, whence they are said to move them from place to place. The plumage is of a dull character.

The Alcedinidæ, or Kingfishers, build nests in holes, laying pure white eggs. Their plumage is brilliant, and the females are coloured like the males. They have no nest to speak of beyond an accumulation of the pellets thrown up by the birds. The Momotidæ, or Motmots, nest in a hole in the ground. Their eggs are white; the plumage is brilliant, the female being like the male.

The Bucconidæ, or Puff-birds, nest in the ground. Their plumage is generally dull, but conspicuous by reason of light bars and stripes, and in both sexes is alike.

The Trogonidæ, or Trogons, are among the most brilliant of birds, the female having also bright colours; they nest in holes in trees, and have white eggs.

In the Upupidæ, or Hoopoes, the sexes are alike in plumage, which is conspicuous. They nest in the hole of a tree; but, although the appearance of the Hoopoe is neat and rather showy, the nest is often composed of the most disgusting materials.

The breeding habits of the large-sized Bucerotidæ, or Hornbills, are among the most curious of any known. During the period of incubation the female betakes herself to the hole of a tree in which she is plastered up by the male, with only a small aperture for the purpose of light and air, and for receiving the food brought by the male bird. Here one egg only is laid.

The gaudily coloured Capitonidæ, or Barbets, lay white eggs, which are deposited in the hole of a tree. The female is brightly plumaged like the male.

In the Rhamphastidæ, or Toucans, both sexes are ornamented with bright colours. They nest in a hollow tree.

The Musophagidæ, or Plantain-eaters, were once

supposed to build in the hole of a tree, but they are now known to build in the open, making a nest something like a pigeon's. The sexes are alike in plumage, both being more or less brightly-coloured. The colour of the eggs is unknown, but they are doubtless white.

The Centropidæ, or Ground Cuckoos, build domed nests near the ground or in bushes. The eggs are white, and the sexes are alike of dull coloration.

The Cuculidæ, or true Cuckoos, as a rule, make no nest at all, but are what is called, "parasitic," placing their eggs in the nests of other birds, and leaving the latter to hatch them out. The young cuckoo, soon after its birth, ejects the rightful occupants of the nest, and is then brought up by the foster parents. The sexes are similar in plumage, which often mimics that of other birds. The eggs are of various colours, often closely resembling those of the species selected as the foster parent.

Among the Picidæ, or Woodpeckers, the females differ slightly from the males, but are often brightly coloured. The eggs are white, and are deposited in holes of trees, or in the ground, excavated by the birds themselves.

The sexes of the Cypselidæ, or Swifts, are alike in plumage. The nests are generally concealed and of rough construction. To this family belong the Edible Swifts (*Collocalia*) which construct curious nests, the substance of which is glued together by the inspissated saliva of the birds. They form the delicacy out of which the Chinese concoct the famous "birds'-nest soup" (Fig. 3). The Tree Swifts (*Dendrochelidon*) also belong to this family. Although they are birds of moderate size they are said to build the smallest nest in the world, as it is not larger than half-a-crown. This tiny nest, with its one egg, is placed on the top of a post or bough, and the bird has been shot while sitting on it. The whole nest becoming attached to the body of the bird by the breaking of the egg, has given rise to the idea that the nest was fastened to the bird purposely, and that the latter flew about in this condition, and hatched the egg in this way.

The sexes of the Trochilidæ, or Humming-birds, are generally different in plumage, that of the females being much duller than the males, but still retaining more or less metallic tints on the upper surface; sometimes the female equals the male in brilliancy. The nest is composed of felted materials generally ornamented, and attached to branches of trees. The eggs are two, and white.

Coming to the large order Passeriformes, or perching-birds, it will only be possible to give a few notes on some of the principal families. The sexes of the Corvidæ, or Crows, are alike. The plumage is sombre and black in all but the Jays and Magpies, which are brightly coloured. The eggs are mottled-greenish, as a rule, and placed in an exposed nest, generally at some height in a tree. No attempt is made at architectural decoration, though the magpies build a large domed nest of thorny twigs, which render it difficult of access.

Among the Paradisiidæ, or Paradise-birds, the females are much smaller than the males, the latter being very brightly coloured, with the feathers fantastically arranged. Little is known of their nesting habits, and that only from native reports, while the egg is unknown. One species of *Epimachus*, with a very long tail, is said to build in a hole in the ground with an exit at each end. One would suppose, however, that the nesting habits of Paradise-birds would not be very different from those of Crows.

The sexes of the Oriolidæ, or Orioles, are both very bright in plumage, and scarcely different, the female being only a little duller in colour than the male. They build a saucer-shaped nest, generally at some distance up, in the fork of a tree, with white-spotted eggs.

Among the Dicruridæ, or Drongos, the plumage is black, the sexes are coloured alike, the nest is rough and shallow, and generally placed in a rather prominent position, and the eggs are white, with conspicuous spots. These birds depend for protection apparently on their great pugnacity, driving away every intruder.

The sexes of the Turdinæ, or Thrushes, are generally alike in plumage, except in the Blackbird and its allies (*Merula*). The nest is cup-shaped and bulky, generally well concealed and assimilated to its surroundings. The eggs of the Thrushes are rather bright, as in the common Song-thrush (*Turdus musicus*), but in the Blackbirds they are more dull-coloured and less spotted.

Among the large sub-family of Sylviinæ, or Warblers, the sexes are usually coloured alike; but very different in the Chats and Redstarts. The latter lay for the most part blue eggs, and the nest is well concealed in the ground, or in a hole of a tree or building. In the Warblers the eggs are dull-coloured, and the nest well concealed, but, as a rule, rather rough in construction.

The Campophagidæ, or Cuckoo-shrikes, have their sexes alike in plumage or only differing slightly, and both of sober colours, except in the Minivets (*Pericrocotus*), where the plumage is very brilliant. The nests are small and shallow, placed in forks of

Fig. 3.—The Edible Swifts and their Nests.

The Paridæ, or Titmice, nest generally in holes of trees or in a wall; when built in the open the nest is always domed, and the sexes are alike in plumage, which is often brightly coloured.

The females of the often brilliantly plumaged Nectarinidæ, or Sun-birds, are extremely dull-coloured. Their habits are very similar to those of the American Humming-birds, but the nest is quite different, being a domed purse-like structure suspended from twigs, and very slightly built of thin bents and grass; the eggs are prettily coloured in some cases, dull in others.

In the Meliphagidæ, or Honeysuckers, the sexes are alike in plumage; but their nesting habits are different in the various species, as are also the eggs. The nest is cup-shaped and hung from a branch by the rim, and at other times placed on a branch.

The families above mentioned include most of the typical Perching Birds, the bulk of the remainder being South American, of whose nesting habits we have generally no precise information: but we must not forget the felted nests of Dicæum (Fig. 4), or mud-built nests of the Swallows and Martins, which are constructed with great skill by the little birds, and usually consist of mud agglutinated by the birds themselves, and attached to the walls of houses. We have already alluded to the nesting habits of the Pigeons; and the Game-birds, which are often supposed to have affinities with the last-named family, certainly differ a great deal from them in their nesting habits. Many of the *Gallinæ* are polygamous, whereas the Doves pair so strictly, that their connubial devotion has become proverbial. The Game-birds make no nests as a rule, the eggs, which are very numerous, being generally deposited in a depression of the ground; and although these birds no doubt suffer greatly from the depredations of wild animals, yet the artful way in which the nest is concealed, and the general similarity of the plumage of the female to the surrounding ground, makes it by no means easy to discover such a nest as a Pheasant's or Partridge's.

Fig. 5.—Brush Turkeys (Mound-building Megapodes of Australia).

In the case of the Wading-birds both eggs and young closely resemble the general colour of the locality where the nest is placed, and this is especially true in the case of the Plovers and Sandpipers; in fact, it is only by watching the birds on to their nests by means of a glass that it

is possible to find the eggs of some of these birds. Of course, in the case of the larger and more powerful families of Wading-birds, such as Storks and Herons, no attempt at concealment of the nest is possible, the large size of the structures rendering them very conspicuous. The latter build their nests on trees, generally at a great height, while the Storks affect civilisation, and are usually protected by the population of the towns where they take up their abode. Ducks and Geese lay plainly-coloured eggs, but have generally a large number, the nests being in most cases well concealed. Gulls breed on rocks, as a rule, though some of the marsh-haunting species frequent inland lakes and meres, these birds especially living in colonies. Terns much resemble Plovers in their way of nesting in little colonies by the sea-shore, where they deposit their eggs without any attempt at a nest. The eggs also resemble those of Plovers, and are difficult to find, from their resemblance to the surrounding stones. Petrels resort to rocky islets during the nesting season, where they breed in holes and burrows of the earth, laying in this instance white eggs, which may probably be concealed by the birds for the same reasons as with the *Picariæ*. Penguins congregate in rookeries on rocky islands in the south seas, their representatives, the Auks of the north, resorting to rocky cliffs. The Pelicans and Darters nest in trees, the Cormorants and Gannets on rocks, though occasionally the Cormorants build in trees also. The eggs of these birds are white, and are remarkable for the peculiar chalky nature of their shells. As a rule, the eggs of the Swimming Birds are not remarkable for any great beauty, but exception must be made in the case of the Auks, and there is nothing finer for the student of oology to see than a good series of eggs of the common Guillemot, which vary from white to red, or sea-green, and are mottled, or spotted, or blotched with black. The case of the variation in colour of the eggs of the Guillemot is extremely interesting, as exhibiting certain specified types of colour; and from the fact that some of these eggs are found in the same situations and localities year after year, it would appear as if certain birds laid a certain type of egg, and never varied in the direction of any other variety.

From the general remarks on the families of birds mentioned above we have two great exceptions. Among the Game-birds we have the extraordinary mound-building *Megapodes*, who construct no nests of their own, but place their eggs in large mounds, often four or five feet in height, where they leave their eggs to be hatched by the heat of the sun, and the decomposing heap in which they are deposited (Fig. 5). Among the Wading and Swimming Birds no more extraordinary way of nest-building is known than that of the common Flamingo. This bird has often been considered a sort of out-the-way kind of Duck, its webbed toes somewhat favouring this as its natural position, while its long legs would seem to ally it to the Herons or Storks. In its nesting habits, however, it is totally different from either of the last-named families, for it builds a nest of mud about two feet in height, on which the two eggs are placed, while the bird was declared to sit on them with its long legs stretched out behind. This, however, is now denied by naturalists.

Lastly, we have the Struthious birds or Ostriches, which deposit their eggs on the ground, the duties of incubation being performed by the male bird. The egg of the *Apteryx* is enormous for the size of the bird, and is carried by the female in a different way to that which obtains with most birds, the pelvis being extremely large, and adapted for the reception of the immense egg.

The above few notes on the well-known families of birds are sufficient to establish the proposition already hinted at in the present paper, that it is almost impossible to lay down a theory or a hard-and-fast line with regard to the nesting habits of birds. The facts detailed above, certainly do tend to show that birds with bright-coloured plumage in the female sex do their best to conceal their eggs, especially when the latter are white; but there are notable exceptions, such, for instance, as with the British Titmice, where the Marsh Titmouse (*Parus palustris*), the hen of which is soberly coloured, takes exactly the same precautions as the brighter plumaged Great Titmouse (*Parus major*). In England, no doubt, the worst enemy that the birds have to contend with is mankind, rapacious animals and birds being kept within the narrowest limits; but in wilder countries, it appears to me that the latter are the chief elements against which the birds have to fight, and many of their habits should be studied in connection with their instinctive protection against such marauders. In the East, for instance, there is a birds'-nesting Eagle (*Neopus malaiensis*), to say nothing of monkeys and egg-destroying animals to guard against, and, therefore, many of the birds in that region may have acquired either by actual experience or by hereditary instinct, manners and customs, the *raison d'être* of which it is now difficult to explain.

WATER FLEAS.

By Arthur Hammond, F.L.S.

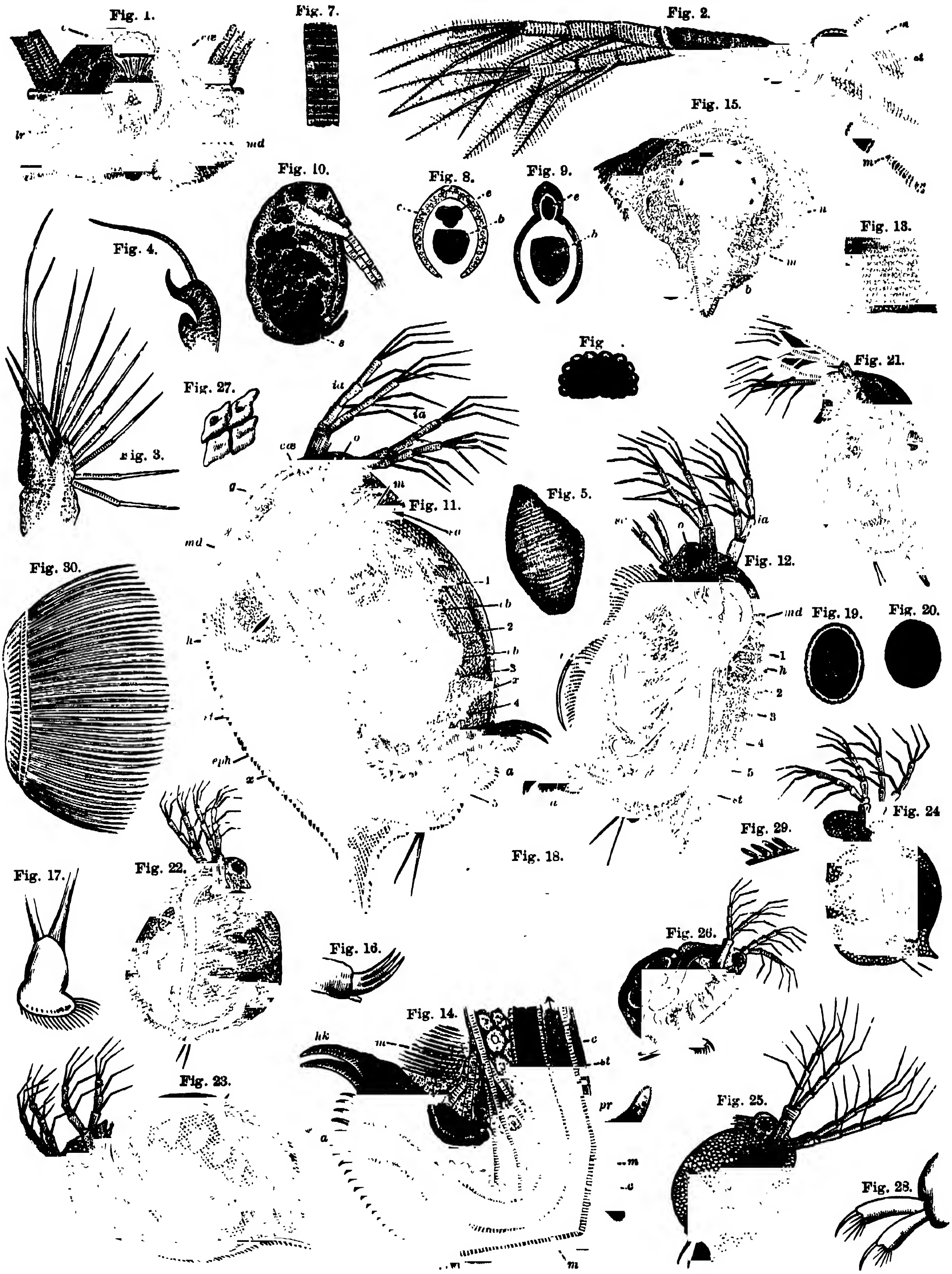
PERHAPS some of the earliest discoveries which will reward the tyro in his search for microscopic pond life, will be some members of the above-named family. They belong to the great group of the Entomostraca, a division of the Crustacea, to which class also the Crab and Lobster belong. The word Entomostraca is derived from two Greek words signifying an insect in a shell, and we shall presently see how well this term is applicable to the little creatures whose history and structure we propose to unfold. Common as they are, it may safely be affirmed that there is no more beautiful or surprising sight than that which they reveal to the astonished vision of those who see them for the first time, nor will the interest thus excited be found to flag under a more extended acquaintance. The exceeding fineness and delicacy of their limbs are specially remarkable, but perhaps the most pleasing and instructive feature they present is the transparency of their tissues, which allows all the functions of life to be carried on under the eye. The whole of the digestive process, from the first inception of the food into the mouth, its trituration by the mandibles, its passage through the gullet into the stomach, its subjection to the vermicular action of the intestine, its digestion, and final expulsion from the body, are all visible; the beating of the heart, the course of the circulation, the movement of the respiratory organs, the contraction of the muscles, the formation of the eggs in the ovary and their subsequent development, are all clearly presented for our instruction and wondering admiration.

The Entomostraca comprise a variety of Crustaceous animals very different from each other in size and appearance: from the extinct *Pterygotus Anglicus*, which probably measured a length of six feet, and the curious King Crab which at the present day adorns our marine aquaria, to the tiny microscopic forms which people thickly our fresh-water ponds, and communicate a ruddy tinge to the waters of the ocean where they form the chief food of the whale. Some of them have branchiæ attached to the appendages of the mouth. Such are the little Cyprides and the *Cyclops quadricornis*, both inhabitants of fresh water, the former looking like a microscopic fresh-water mussel, and the latter with its bags of eggs familiar almost to children, as it obtrudes itself sometimes into the water supplied to our houses. Others again in common with the higher forms of Crustacea, as the Lobster and the Cray-fish, have branchiæ attached to the legs, and such are the Daphniæ with which we are at present concerned.

In a former paper (Vol. II., p. 34) on the anatomy of the lobster, we shall find a number of terms used which will naturally help us in our study of the Daphnia. Many of the statements also made therein, and the lessons drawn therefrom, are applicable in the present instance. Thus, like the Lobster, the animal is encased in shelly armour. Like the Lobster too, it has occasion periodically to get rid of this armour, and for a similar reason, namely, to allow for periodical increments of growth. It has happened to the author of this paper to witness the process, which occupied about half a minute, the integument of the head and the great antennæ coming away separately from that of the rest of the body, with which was associated a saddle-like receptacle for the eggs, called the ephippium, of which more anon. The shelly armour of the Daphnia serves, like that of the larger Crustacea and of insects, not only as a protective covering but as an external framework for the attachment of the muscles; but it differs very much from these in its exceeding delicacy and transparency, to which allusion has been already made.

The definition of the class (Crustacea) to which the animal belongs, carries with it of course the plan of body-structure peculiar to that class in common with the insects, &c., namely, that of an articulate or jointed animal, consisting of a number of segments or joints with paired appendages in which these regions are distinguishable — head, thorax, and abdomen (Vol. IV., p. 22). The great bivalve shell, or carapace, which encloses the greater portion of the body may tend to make the recognition of the plan of structure a little difficult at first: a difficulty which is further enhanced by the obscure segmentation, or "ringing," of the body; but the series of appendages we now proceed to describe will make it sufficently evident that we are dealing with a member of the articulate or "jointed" sub-kingdom.

The head is the only portion of the animal which



Water Fleas and their Anatomy.

(For explanation of the different figures, see page 373.*)*

is not enclosed within the carapace, and possesses two pairs of appendages, the superior and inferior antennæ. The former are very minute in the female, though larger in the adult male, and are placed at the extremity of and a little underneath the beak-like process in which the head terminates. They are seen at *sa* in Figs. 11 and 12, and in Fig. 28. The latter (*ia* in Figs. 11 and 12, and in Fig. 2) are very conspicuous organs, and are inserted near the junction of the head and body. They consist each of a single joint at the base, dividing subsequently into two branches, of which one is divided into four joints and the other into three. Both branches are furnished with several jointed and beautifully-feathered filaments. These antennæ are in constant motion, and act not as feelers, as do the antennæ of the Lobster, but have a different use or function assigned to them, viz., that of locomotion, of which they are the chief agents; whence we may learn this important lesson, that parts that correspond with each other in different animals may not necessarily have the same function. To take a more familiar instance: the wing of a bird and the arm of a man are doubtless corresponding parts, but the one is an organ of aërial progression, the other an instrument of prehension. In the basal joint and the two branches of these antennæ we are again reminded of the protopodite, exopodite, and endopodite of the limbs of the Lobster.

The next pair of appendages are the mandibles (Figs. 11, 12, *md*). In common with those following, they are enclosed within the carapace, and are therefore not so clearly visible as the antennæ immediately beneath the insertions of which they are placed. Each consists of a stout bent piece, moved by powerful muscles in such a manner that their serrated ends are brought into grinding contact with each other, beneath the labrum or lip to be presently described. Every now and then a little pellet of the decaying flocculent substances on which the animal feeds, may be seen to pass between these grinding edges into the œsophagus and stomach. To use Mr. Slack's words concerning the gizzard of some of the Rotifers, or Wheel-animalcules: "As the joints of this machine move and the teeth are brought together, one could fancy a sound of mill-work was heard, and the observer is fully impressed with a sense of mechanical power." Some of the Daphniæ, for example *D. vetula*, have a happy knack of lying on their back in the live-box, in which position the action of the mandibles can be seen in front view to great advantage (Fig. 1, *md*).

Following these are a smaller pair of appendages, the maxillæ or jaws (Fig. 16), and then come five pairs of legs, corresponding in position to the thoracic or chest limbs of the Lobster; their use, however, as organs of motion has been altogether suppressed, that function having (as already stated) been transferred to the great antennæ. By their means, however, the important work of conveying nutritive particles to the mouth, and the equally necessary processes of respiration are conducted.

The prehension of food, which in the Lobster is effected by the chelate thoracic limbs, is brought about by very different means in the Daphnia. Instead of being seized, the nutritive particles are drawn in by the action of the feet between the valves of the shell, and collected in a mass before the mouth, in readiness for the mandibles to operate upon. It is probable that the whole of the feet, by their constant undulatory motion, contribute more or less to this result, by which means also the constant access of freshly-oxygenated water to the gills is maintained. The form of these feet is so complicated that we can only here notice the most salient points of their construction. The first pair, Figs. 3 and 4, offer one of the most distinctive points of difference between the sexes, being furnished with a hook and a long filament which floats outside the shell in the male, both of which features are absent in the female. The three following limbs, viz., the 2nd, 3rd, and 4th pairs, are each provided with a delicate comb-like inner branch, little developed in the 2nd pair, but very conspicuous in the 3rd and 4th. These have been termed the branchial plates (see Fig. 30). By their undulatory movement they doubtless serve to keep up a constant flow of fresh water through the valves, and so must be regarded as important accessories to the work of respiration, but that they are the organs in which that process is carried on seems very doubtful. But little blood can possibly circulate through the fine cavities of the comb-like teeth, and we must remember that one of the first requisites of a branchial organ is that it should provide ready access for the impure blood within its tissues to come into contact with the vivifying water outside, a condition much more easily complied with by certain pouch-like organs with which each of the five pairs of feet is externally provided. They are easily seen through the shell (see Fig. 12), and partake of the movements of the limbs to which they are attached. By careful observation, a full stream of blood can be seen circulating within their soft and delicate walls.

Leaving now this doubtful point, if we try to conceive the carapace of the Lobster enormously produced backwards and laterally, so as to cover the abdomen and the legs, we shall have some idea of the relationship of the shell of the Daphnia to the body which it encloses. In conformity with this idea, we observe that while the head and thorax, as far as and including the heart, are intimately united with the carapace, the abdominal segments containing the posterior portion of the alimentary canal are freer and have a certain limited amount of motion, the tail (Fig. 14) if we may so call this portion of the little animal, being frequently protruded from between the valves and withdrawn again, and sometimes passed up between the combs as if for the purpose of raking out, by means of the pair of terminal teeth with which it is armed, any offensive particles which may have found their way in with the food. This portion of the body, it will be observed, is soft and flexible, to allow of the mobility referred to, the covering of the carapace rendering any further protection unnecessary. A similar softness and mobility of the abdominal segments may be observed in most beetles, when the horny wing-covers and the wings are removed. Each valve of the carapace consists of an external and an internal wall, as shown in Figs. 8 and 9, the former stout and resisting, and covered with a mesh (Fig. 27) of lozenge-shaped reticulations—the shape, however, varying in different species—and the latter soft and membranous. There is thus a space between the external and internal walls of the carapace, within which streams of blood-corpuscles are constantly carried round, as may easily be seen with a little careful attention. The valves are not united by anything like a hinge, as in an oyster, but form one piece, and open merely by their elasticity. They are terminated generally by a long spine, but in some species this is wanting. In the new-born young (Fig. 10), this spine, which is then very long, is coiled up between the front margins of the valves, but soon after they have begun to move about in the water, it may be seen to spring forth with a sudden jerk and assume its natural position. The margins of the valves are frequently set with fine hairs and with teeth like those of a saw (Fig 29).

The stomach (*st*, Fig. 11) is a large curved vessel, somewhat straight in the middle part of its course, but bent round at either end. There is no division into stomach and intestine, the same cavity serving for both purposes. It is here that the food is digested, and through the walls of this cavity the products of digestion are absorbed into the circulation. The mouth is concealed, but its position is marked by the grinding of the mandibles, which, as before stated, play upon the food as it enters (*m*, Fig. 11). It is covered by a fleshy labrum or lip (Fig. 17), which is only seen when it is occasionally raised, and it is succeeded by the gullet, which after running upwards into the head, curves round and widens into the stomach. At the head of the curve two blind tubular processes called cæca (*cæ*, Figs. 1, 11) occur, the use of which is not known. The stomach, through the greater part of its length, may be seen, under favourable conditions, to be surrounded with a coating of muscular fibres (Fig. 13) running round it in a circular direction, by the successive contraction of which the contents are kept in continual movement, similar to that which occurs in man and the higher animals, and is known as the peristaltic movement of the intestine. Sometimes its contents are of a fine green colour, caused probably by the presence of the colouring matter, or chlorophyll of various vegetable organisms, introduced with the food and dissolved by the action of the gastric juice.

Perhaps one of the most interesting points of the Daphnia is the clearness with which the heart's action may be seen. In most of the lower crustacea the heart is a vasiform tube, like the dorsal vessel of insects.* In the higher forms, however, and in the Daphnia, it is a muscular sac, lying beneath the carapace and giving origin to trunks which convey the aërated blood to all parts of the body. That of Daphnia may be seen at the back of the animal (Figs. 5 and 11) pulsating most vigorously. About its centre a slit-like orifice opens and closes with each beat, and admits blood from a surrounding chamber called the pericardial sinus into the interior of the heart, whence it is expelled in an anterior direction. The course of the blood through the heart, and indeed that of the circulation generally, is indicated by the white corpuscles floating in the fluid which correspond very closely with similar corpuscles existing in our own blood. In this way we can follow it in part, but not through its whole extent. One stream is thus seen to supply the head and parts connected with it, another bathes the stomach, the respiratory organs, &c., and another again makes the circuit of the valves, returning by the back of the shell to the pericardial sinus and the heart.

* "A Cockroach," "Science for All," Vol. III., p. 325.

The muscles which move the great antennæ are very conspicuous, originating at the back of the head, and passing in converging bundles to their insertions at the base of these organs; they are shown at *m*, Fig. 2. Other smaller bundles occur in the feet and in the abdomen, and under a high power of the microscope may be seen to possess the striated character so generally found in muscular tissue (Fig. 7).

The eye of the Daphnia (Fig. 15) is an object of much interest; it is apparently a single organ occupying a conspicuous position in the front of the head; it is of a nearly spherical shape, and composed of about twenty crystalline lenses arranged around a central mass of black pigment; it is furnished with muscular bands, by which its movements are effected, and which by their contractions cause in it an alternating fidgety movement in a rotatory direction. From its lower surface arise a number of fine nervous cords, the optic nerve, connecting it with a nervous knot or brain immediately below. Although apparently single, and described as such by many authors, the following facts observed by the writer of this paper seem to lead to the conclusion that it is essentially a double organ formed by the coalescence of two originally distinct ones. The young of *Daphnia vetula* immediately after birth were seen to be possessed of two red eye specks separated by a considerable interval, not as yet furnished with lenses, but more like the simple form of the eye observed in Cyclops and other fresh water Entomostraca. A front view of the eye of *Daphnia psittacea* also, as seen in Fig. 6, gives the impression of its being formed by the coalescence of two distinct eyes.

The eggs of the Daphnia are first to be seen in the shape of small round pellucid globules which mark the situation of the ovaries placed along the sides of the stomach. They soon lose their transparency, and form a dark oval mass, which shortly quits the ovary and is transferred to the empty space between the back of the animal and the shell, where they are kept in their position by a projecting process (*pr*, Fig 14) of the abdomen. Here they remain for four or five days, till ready to emerge as independent beings. Five or six eggs may sometimes be seen together in this empty space, which, although enclosed by the shell, is, it must be borne in mind, exterior to the body of the animal, and may be called the incubating chamber. Here too, the process of development may be watched, the eggs, which are at first round and filled with globules, becoming subsequently more oval, and the globules augmented in number. Soon traces of the eye and the limbs appear, motion becomes perceptible, and the heart may be seen to beat. At the end of the fifth day the young are launched into the water nearly in the form of their parents. All the eggs, however, do not follow this course. At certain seasons a peculiar thickening takes place at the back of the shell, which gradually assumes a dark colour, and one or two of the eggs are found enclosed within it. This is called the ephippium (Figs. 11, 18), from a Greek word signifying a saddle, from its fancied resemblance to that object. The cavity of the ephippium is at first continuous with that of the incubating chamber, but it gradually closes upon the eggs until they are entirely shut off therefrom. At the next moult the ephippium with its eggs is thrown off from the animal, and floats on the surface of the water, where it is said to remain till the following spring, when the young are hatched by the returning warmth of the season, thus affording an excellent example of the care with which nature provides for the preservation of her smallest creatures. The ephippial eggs (Fig. 19) differ somewhat in appearance from the ordinary ones, being enclosed in a hard horny shell, which, in addition to the protection of the ephippium, renders them peculiarly fitted to withstand the vicissitudes of winter.

We will conclude with a brief description of the seven species of Daphnia peculiar to Britain, all of which may be found with a little search, but some are much more common than others. The first of these is *Daphnia pulex*, and is very abundant in all parts of the country. The head in this species is large, rounded above, but produced below into a sharp pointed beak. The valves are marked with a meshwork of crossing lines, and their margins are smooth, not serrated as in the following species. Sometimes a red colour prevails to such an extent as to communicate a ruddy tinge to the water in which the animals abound. The male is much smaller than the female, and may be recognised not only by the floating filament of the first pair of feet before mentioned, but by the straight outline of the anterior margin of the valves as compared with the female.

Daphnia psittacea is frequently met with, having been found by the writer in ponds at Streatham and at Sheerness. The head is large and somewhat square-shaped, the anterior part is beaked like the beak of a parrot. The margins of the valves are

closely serrated or set with teeth like those of a saw. The pond at Streatham contained a large number of males.*

Daphnia Schæfferi is the largest of the family. The valves are nearly circular, and their margins serrated. The head is comparatively small, and flattened on the summit. It may be easily recognised by the peculiarity of its movements, which differ from those of the foregoing species, and are distinguished by an awkwardness and head-over-heels manner of progression, anything but dignified. The carapace sometimes exhibits a white opacity, which obscures the body of the animal within.† It has been found at Bexley Heath, in Kent, and by the author at Sheerness and Gosport, Hants.

Daphnia vetula is common about London. The head in this species is small compared with the carapace, which is cut off flat at its extremity, and destitute of the terminal spine. The valves are striated rather than reticulated.

Daphnia reticulata is a small species, the valves of which are covered with a mesh of hexagonal cells.

Daphnia rotunda differs from the last in the round outline of the shell; it is also slightly larger.

Daphnia mucronata is a singular form, the anterior margins of the shell being quite straight, and terminating below in a long spine. There are thus two of these spines which replace that usually found at the back. This species has been found by the author of this paper in ponds in the Crystal Palace grounds at Sydenham.

* Baird says that the males are scarce, and only to be found at certain seasons, generally in autumn. I have, however, found males of *D. pulex* and *psittacea* in May and June, those of the latter species occurring abundantly.

† Baird, however, describes it as transparent.

EXPLANATION OF FIGURES (p. 369).

[illegible]
Eye; *cæ*, the Cæca; *md*, the Mandibles; *lr*, the Labrum.

Fig. 2.—One of the Inferior or Great Antennæ of *D. pulex*: *m*, [illegible] Muscles; *st*, Stomach.

Fig. 3.—First Foot of *D. Schæfferi*, female.

Fig. 4.—Ditto of *D. psittacea*, male.

Fig. 5.—Heart of *D. psittacea*, showing Slit.

Fig. 6.—Eye of ditto, showing its double character.

Fig. 7.—Striated Muscle of *Daphnia*.

Fig. 8.—Transverse diagrammatic section of Shell of *Daphnia* along the line *x*, *x*, Fig. 11, showing its double wall; *e*, Eggs; *b*, Body; *c*, Blood Corpuscles.

Fig. 9.—Ditto, showing the Ephippium closing upon an Egg.

Fig. 10.—Young of *D. pulex*, showing *s*, the Coiled-up Spine.

Fig. 11.—*D. psittacea*, female. *o*, the Eye; *sa*, the Superior Antennæ; *ia*, the Inferior Antennæ; *cæ*, the Cæca; *md*, the Mandible; *m*, the Mouth; 1, 2, 3, 4, 5, the five pairs of Feet; *cb*, the Branchial Plates, or Combs; *g*, the Gullet; *st*, the Stomach; *a*, the Anus; *h*, the Heart; *eph*, the Ephippium, with two Eggs.

Fig. 12.—*D. psittacea*, male, showing *sa*, the Large Superior Antennæ; the Filament, *f*, attached to the first pair of Feet, and the pouch-like organs of the Feet. Other letters as before.

Fig. 13.—Portion of Stomach, showing Muscular Fibres surrounding it.

Fig. 14.—Terminal Segments of Abdomen of *D. pulex*: *a*, the Anus; *hk*, Anal Hooks; *st*, the Stomach; *pr*, Process for retaining the Eggs; *c*, the Body Cavity, with Blood Corpuscles streaming towards the Heart; *m*, *m*, Muscles.

Fig. 15.—Eye of *D. vetula*: *m*, Muscles; *n*, Optic Nerve; *b*, Brain.

Fig. 16.—Maxilla, *D. Schæfferi*.

Fig. 17.—Labrum, ditto.

Fig. 18.—Ephippium of *D. psittacea*.

Fig. 19.—E [illegible]

Fig. 20.—O [illegible]

Fig. 21.—*D.* [illegible]

Fig. 22.—*D.* [illegible]

Fig. 23.—*D.* [illegible]

Fig. 24.—*D.* [illegible]

Fig. 25.—*I* [illegible]

Fig. 26.—*I* [illegible]

These six foregoing figures represent females bearing ordinary, or Summer Eggs.

Fig. 27.—Reticulations on Shell of *D. psittacea*.

Fig. 28.—Superior Antennæ of young *D. pulex*.

Fig. 29.—Marginal Teeth of Shell of *D. psittacea*.

Fig. 30.—One of the Branchial Plates, *D. pulex*.

CONCLUSION.

BY THE EDITOR.

In the volumes now brought to a close we have ranged over many fields of science, reaping here and gleaning there, now binding a sheaf, anon snatching a handful as sample of the crop still standing. The labourers have been many, but the harvest is heavy. To have garnered all that lay ripe to our hand would have been impossible within the time at our disposal, and the space allotted for its accommodation. It would, moreover, have defeated the object aimed at here, for, instead of a work of that nature providing Science for All, it would necessarily have been a technical encyclopædia accessible to few, and unintelligible to many. On the contrary, in accordance with the promise made in the programme, we have endeavoured to select certain subjects capable of simple explanation, and to employ them as pegs on which to hang the scientific principles of which they were the embodiment. We have tried to write on lines much the same as the reader's mind would take were he or she trying to puzzle out the subject for himself or herself, and, while seeking as far as possible to avoid needless minutiæ, to be as careful in regard to facts and conclusions as if we were addressing an audience of experts. A popular paper is not a technical essay watered out with words and pointless anecdotes; but neither does it follow that a mass of data heaped together in the most repulsive literary form is necessarily on that account scientific. Science is simply knowledge, and the more lucidly that knowledge can be conveyed, the more completely does the teacher demonstrate the clearness of the mental process by which he has arrived at his results. Yet while this work does not profess to be exhaustive, it will, we believe, be found that no subject of popular interest has been entirely neglected, and an examination of the indices will show that often under the least pretentious heading, there has, for the first time, been explained the most recondite of the many brilliant discoveries of recent times. That in some respects the publication has fulfilled its design is proved not only by the favour which it has received in this country, in the United States and the Colonies, but by the fact that many of the papers have been reproduced in almost every European language, and in some of those of the farthest East, and that the only English monthly serial which has ever been regularly translated into any foreign tongue has been "Science for All," which, in Danish and Swedish versions, circulates as a familiar friend among the Scandinavian borger and bönder from Jutland to the Norrland, and is read even in Greenland and Iceland. It is impossible for anyone who does not devote his life to learning to become the master of any one science. Time was when the sum total of our knowledge of nature could be compressed within the compass of three small volumes, like those comprising the "Systema Naturæ" of Linnæus. A "philosopher" in those days was the trustee of the treasures of human research, and men who, like the late Drs. Gray and Fleming, commenced life by the determination to acquire all that was known, were forced long before they laid aside their pens to confine themselves to one science, or even to one section of science, by the hopelessness of ever keeping pace with the thousands of panting toilers who were daily adding to the ever-accumulating piles of information. Take Botany, for example. Hippocrates, who lived between four and five hundred years before Christ, mentions only 234 species of plants, and Theophrastus, two hundred years later, vaguely describes about 500. Pliny, even in the golden reign of Vespasian, after having at his command all the resources of the Roman Empire, could not enumerate more than 800, which is also nearly the limit of the catalogue issued by Conrad Gesner after another interval of 1,500 years. At the beginning of this century there were only 26,000 species of all kinds of vegetables known: at the present moment fully 100,000 different forms of flowering plants, and 25,000 cryptogams or flowerless ones, like mosses, fungi, and sea-weeds, are described and figured in the works of botanists. Zoology has advanced with strides quite as rapid. In 1831, there were not more than 70,000 species of animals on our lists: to-day Dr. Günther considers that 320,000 will be a nearer approximation to those of which the zoologist ambitious of the vain task of numbering every form pourtrayed would require to take cognisance. In the British Museum alone it is estimated that there are no fewer than 12,000 species of insects which have not yet been named, and some of the best entomologists calculate that there must be at least one million species of that order of animals. Yet all of this is apart from the new world of biology, which has been explored by the anatomist and physiologist, and which is hourly opening up new lands of wonder. In the days when men still working were boys at school,

geology had barely assumed a stable place among the sciences, and palæontology scarcely existed, so few were the ascertained forms of extinct life. In 1843, as Sir John Lubbock has lately reminded us, there were only 5,300 recognised British fossils: to-day 16,000 are in our museums, and 26,000 altogether described from the rocks of the world, though so rapidly are discoveries being made that in a few years this estimate will be obsolete. The chances are, making liberal allowances for the number of species in the early stages of the earth's history being fewer than in its later ones, that by the "slow results of time," 2,000,000 species of plants and animals have lived and died in the earth, and in the waters upon the earth, since first there went forth the mandate, "Let there be light."

However, the plan of a city may be understood without the student requiring to count the number of houses, or to examine every window, door, and brick in each of the buildings composing the streets and squares. Neither is it necessary to know all the endless forms of Crustacea to understand their general structure and history. The student who has made himself familiar with the anatomy of a lobster, or of a water flea, will not have a great deal to learn, while, should he desire to extend his acquaintance with the order, he will find it easy to master the individual differences which the other species present. Classification shows them all united by one common plan of structure, so that once this is understood, the anatomy and even the physiology and habits of the others become more the province of the specialist than of the "general reader" to study. But of late years "species-men" have rather fallen into disrepute. They are regarded by the "scientific naturalist" in much the same light as the architect regards the hodman, who brings up the marble and mortar, out of which the palace he has planned is to be reared. The heaps of timber, lime, sand, stone, and slates are no more a house than the unassorted, unsifted mounds of facts constitute a science. The philosopher connects the one with the other, studies their various relations, and, by a logical process, as strictly on the lines of the Baconian "Novum Organum" as any inference of the metaphysician, deduces certain general conclusions regarding the laws of nature and the history of the Universe. To reverently pry into these arcana, and, as far as possible, to apply the facts ascertained for the gratification of man's intellectual longings, and the improvement of his condition, is the legitimate aim of all science worthy of the name. Hence, though the material we have to deal with is infinitely greater than it was twenty years ago, it is much easier nowadays to state within a moderate compass the broad conclusions in the chief sciences than would have been possible at that date. Nor is research more difficult.

The instruments which have been devised by the ingenuity of modern mechanicians enable us to probe far more deeply into the secrets of nature than could our forefathers. These tools are capable of the utmost precision. But they are costly, and require a training in itself before the observer can use them to good purpose. The earlier observers were forced, either by choice or by necessity, to use simpler apparatus. When foreign visitors asked to see Radcliffe's laboratory they were pointed to a few phials on a shelf. Dalton, the father of modern chemistry, was possessed of a scarcely less costly array of aids to study, and the entire apparatus by which Cavendish, the wealthiest physicist in England, ascertained the composition of water was certainly not worth in the open market more than a few shillings. But the facts within reach of such humble appliances have for the most part been seized long ago, and if actual research is aimed at, something more elaborate must be obtained. Still, there is scarcely an observation or a principle enunciated in these volumes which the poorest student could not confirm or repeat for himself with the expenditure of a little labour and a small amount of money. Every stagnant pool, every rocky sea-shore, every fallen leaf, and roadside flower, afford objects for study, to which a pocket lens, a pair of scissors, and a needle stuck in a bit of stick, are about all the adjuncts required. Geological research requires really no apparatus beyond a hammer and chisel, and as every railway cutting and rock face is a free field for the tyro to test the lessons of his book, the cost of a department of natural history as fascinating as any, and perhaps more likely to lead to really valuable discoveries than most others, need be actually *nil.* A perusal of the papers on physical science will show that an earnest student with even the minimum of ingenuity can utilise cheap materials for the preparation of most serviceable apparatus, and in a special paper upon the subject of astronomical observations with simple instruments it has been shown that even the distant stars can be brought within our ken, at a cost far less than is usually supposed to be demanded for telescopic and other assistance. A summer afternoon devoted to an intelligent examination of a rocky coast will teach as much about "marine erosion" as the most extensive voyage is likely to do, and the observer, if he has read aright the lessons taught in these pages, need not travel to the Amazon or the Mississippi to understand the action of rivers, or the laws governing the movements of running waters. A mountain "burn," or even the rain coursing along the gutters of the street, will form an instructive illustration of many a chapter in physical geography. The learner must not despise little things, or consider that a fact is important simply because it looks large or specious; for what seems to-day of little moment, may to-morrow, in the light of other data, become of the greatest value.

Mr. Darwin has published an instructive commentary on the statement. He has shown that the humble earthworm is one of the most important agents in the natural tillage of the soil, by swallowing earth, bringing it to the surface, and then voiding it in the little castings with which we are all familiar. In this manner it is probable that a considerable part of the surface soil has passed and is passing through the intestines of worms, and that by burying and thus preserving ancient remains, the archæologist, equally with the farmer, owes the *Lumbricus* a lasting debt of gratitude. But though the theorist may be the salt of the scientific world, the "hodmen," who bring us the facts, are the essential factors in its life. Without data, the enunciations of the theorists become simply idle hypotheses, like the puerilities of the schoolmen, and the speculations of the naturalists and astronomers before they based their conclusions on a structure of realities. It is therefore essential that these facts should be carefully recorded, without regard to pre-conceived ideas, or the possible "view" they may be used to support, for, as Bacon has it, "the true philosopher is he who loveth truth better than his theory." Unless our data are accurate, everything we deduce from them will be tainted with error. "We cannot deceive Nature, however much we may deceive ourselves." It is a serious matter to send an untruth floating around the world poisoning the source of knowledge, and, it may be, shunting into wrong tracks the anxious seekers after light. Yet unconsciously, by error in observation, by haste, by ignorance, this is done every day. "Physical science," to use the words of our fellow-labourer—Professor Josiah Cooke, of Harvard—and I can find none better to express what it is desired to bring out, "is noble because it does deal with thought, and with the very noblest of all thought. Nature at once manifests and conceals an Infinite Presence. Her methods and orderly successions are the manifestations of Omnipotent Will. Her contrivances and laws are the embodiment of Omniscient Thought. The disciples of Aristotle so signally failed simply because they could see in Nature only a reflection of their idle fancies. The followers of Bacon have so gloriously succeeded because they approached Nature as humble students, and having first learned how to question her, have been content to be taught, and not sought to teach. The ancient logic never relieved a moment of pain, nor lifted an ounce of the burden of human misery. The modern logic has made a very large share of material comfort the common heritage of all civilised men."

Nor need the reader fear to range over a wide area by the absurd dread of a little knowledge being "a dangerous thing." It is not half so dangerous as ignorance, and can never do the possessor or anyone else the slightest injury if they do not foolishly believe that it is great instead of little. It is true, as Sir John Lubbock has expressed it, that he who cultivates a small piece of ground is more likely to trench deeply than his neighbour, ambitious of farming a broader field. But this does not necessarily follow, for—to go no further than the eloquent President (1881) of the British Association himself for an example—it is quite possible to be eminent in the bye-paths of many different departments of research. Too close application to a speciality tends to narrowness and bigotry. The "Scarabæist" of Wendell Holmes, who scorned the idea of being styled an entomologist, and would hardly allow that he was a coleopterist, was not, if we recollect rightly, a gentleman of the broadest sympathies, or the most cultured intelligence? We are, however, speaking not to a society of savants, but to an audience of intelligent men and women more anxious to learn something about the wonders above, around, and beneath them, than to add to the sum of science. On our part it has been our desire to advance knowledge by making what is locked up in quarters where it is seen by the few, accessible to the many. We therefore counsel no Icarian flights, since, as Sir Arthur Helps so aptly puts it in one of his charming essays, it is ever the tendency of mankind to pass over the flowers in their path in search of the plant that blooms but once in a hundred years.

Knowledge, as the Lord of Verulam wrote so earnestly three centuries ago, is not "a couch whereupon to rest a searching and restless spirit; or a terras, for a wandering and variable mind to walk up and down with a fair prospect; or a tower of state for a proud mind to raise itself upon; or a fort or commanding ground for strife and contention; or a shop for profit or sale;" but "a rich storehouse for the glory of the Creator, and the relief of man's estate." Science has advanced so rapidly of late that sometimes we forget in our pride of conquest how much is still to be grasped. What indeed we know is as nothing to what shall yet be vouchsafed to us, when the something "in this earthy ball shall be unriddled by-and-by." Nature accomplishes nothing by leaps and starts, cataclysms and catastrophes; but by the slow, continuous action of fixed laws, all connected, and all working seemingly independent, yet in reality towards a common end. There are no accidents, nothing haphazard, and consequently nothing happening by "chance." The result of these factors is the beautiful harmonious whole, the mystery of which it is the daily work of the natural philosopher to unravel, and the full wonders of which may in the future be revealed to him.

INDEX.

A

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TO SUBJECTS.

VOLUMES I. TO V.

A

A

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